AMATEUR
CARBRO COLOUR PRINTS

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AMATEUR CARBRO COLOUR PRINTS

By

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Second Edition

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Nearly everyone who has become interested in colour transparencies will have asked whether it is possible to produce prints in colour.

Admittedly the process has its snags, but any photographer who can make first-class bromide prints and is willing to follow the instructions carefully should be able to make satisfactory colour prints with a little practice. Cost of materials used in actually making a half-plate print is only about 3s. 6d.

This book is designed to help him taking the first steps as much as it hopes to assist the more advanced worker towards improving his results.

In particular, the second half of the book is primarily intended to help the more advanced. It is strongly recommended that unless the novice is particularly interested in a theoretical approach to the three-colour processes, he should leave the parts in question unread until he has made some practical experience in making colour prints.

Materials for the Carbro process are made in nearly every country ; here in Britain the Autotype *materials are the only ones available. This is the sole reason for referring to them in the text. Slight modifications to the working procedure may be necessary when using other makes of material, but the same general principles apply.*

The author gratefully acknowledges the help he has received from many quarters in writing this book. In particular his thanks are due to Somerset Murray, F.I.B.P., W. J. Pilkington, F.R.P.S., The Autotype Company, Ilford Ltd. *and* Kodak Ltd.

*

In the edition I have made a few minor alterations to the text and have also included new matter on Sensitisers, Even Development, the use of the grey printer, and a chapter at the end of the book on Accuracy in Colour Reproduction.

Although I realise the inclusion of the latter in a book devoted solely to Carbro may be open to criticism, I feel that there are many amateurs, like myself, who can never rest content until they know more about the theoretical limitations of the subtractive colour printing process and the way in which it may be possible to improve it.

Although the methods for working out a masking system were first described in a paper by Mr. Anthony Marriage, F.R.P.S., *in 1940, I do not think they have yet been adopted by the practical worker.*

My acknowledgments and thanks are due to Mr. Marriage both for the use I have made of his original paper, and for the help he has given me in writing this Chapter.

Hong Kong, June 1951. *Hanworth.*

THE PROCESS

The production of really first-class colour prints is rather an exacting process calling for considerably more patience and time than is required for ordinary photography. It also needs absolutely clean, tidy and accurate work and quite an amount of experience in monochrome photography.

There are, however, immense opportunities for original work, particularly in the pictorial field, and a good colour shot can command a very high market price. Trichrome Carbro is generally acknowledged to be capable of producing results which are equal if not superior to any other process yet put on the market.

THREE-COLOUR REPRODUCTION

The possibility of the three-colour process was first demonstrated by *Clerk Maxwell* in 1871, when he showed that by the admixture of three suitably chosen coloured lights any colour could be reproduced. The colours so obtained are not physically identical with the so-called monochromatic colours obtained by splitting white light with a prism, but the effect on the eye is identical.

This forms the basis of one theory of colour vision, which assumes that our eyes have three sets of nerves, sensitive respectively to red, green and blue. These are known as the *primary* colours. Clerk Maxwell's method of colour synthesis is known as *additive*, since it depends on superimposing or adding the coloured primaries.

The *subtractive* process uses the complementary or

minus colours, cyan, magenta and yellow as its primaries. These are akin to the primary colours used by an artist when mixing paints and are also sometimes referred to as secondary colours. To obtain them, white light is assumed to be composed of the three additive primaries red, green and blue ; each one of them is then subtracted in turn :

RELATION OF COLOURS

White Light	*Additive Primaries*		*Subtractive Primaries*
Red, green and blue	*minus*	Red	*equals* Blue-green or cyan
	minus	Green	*equals* Red-blue or magenta
	minus	Blue	*equals* Red-green or yellow

Each of the complementaries should in theory transmit or reflect its own colour and completely absorb the corresponding primary colour.

In a subtractive colour process therefore three negatives are made through filters to record the red, green and blue components respectively. Prints from the negatives are then dyed and superimposed.

All subtractive colour printing processes use the additive primaries for the taking filters and print in the complementary colours.

The logic of this can be seen if we consider the case of a photograph of a red object taken through the tricolour filters. In the negative taken behind the red filter the subject will record as a relatively heavy density and consequently will come out near white on the corresponding print. In other words the blackness on the print will be inversely proportional to the amount of red in the subject and therefore is a measure of the *absence* of red. A suitable printing colour for the red filter negative will be one which will absorb increasing amounts of red as the density of printing is increased. This complementary colour is of course cyan, since it is formed by subtracting the red from white light.

Similar logic may be applied to the other primary colours.

OUTLINE OF THE TRICHROME CARBRO PROCESS

The first step in the process is to make the separation negatives.

These are obtained either direct from the subject by photographing it three times through tricolour filters (red, green and blue) or from a colour transparency.

The actual process of making the colour print may be divided into four stages. It is quite permissible to carry them out at different times.

1. MAKING THE BROMIDES.—Three bromide prints are made, one from each filter negative, the relative exposures for the prints being so adjusted that any part of the subject which is colourless i.e., white, grey or black, will have equal density in each of the three prints.

2. MAKING THE COLOUR RELIEFS.—Trichrome Carbro pigment papers, also known as tissues (the colours are cyan, magenta and yellow) are immersed in a sensitising bath and each squeegeed in contact with the bromide print which was made from the negative taken through the complementary coloured filter. After a short period of contact the prints and pigment papers are separated, the latter being squeegeed on to individual transparent supports made of plastic, and the bromides which are now in a bleached condition are washed preparatory to re-development. The pigment papers on their supports are then developed by immersing them in warm water, peeling off the backing paper and washing away the surplus coloured gelatin which has not been rendered insoluble by contact with the silver image of the bromide print. At this point there are three separate coloured images of the subject, each adhering to its own support. These are allowed to dry.

3. COMBINING THE COLOUR RELIEFS.—The three colour images are superimposed on a single coated paper support. This part of the process, which is reminiscent of a child's transfer, is done by giving the coated paper a preliminary soaking in water and then squeegeeing it in contact with the coloured image on its transparent support. The two are allowed to dry, when the image will adhere to the paper and leave its old support. The same procedure is followed with the other two colours which are of course registered with the first image on the same support. There is no objection to allowing a day or so to elapse between transfers, if for any reason this happens to be convenient.

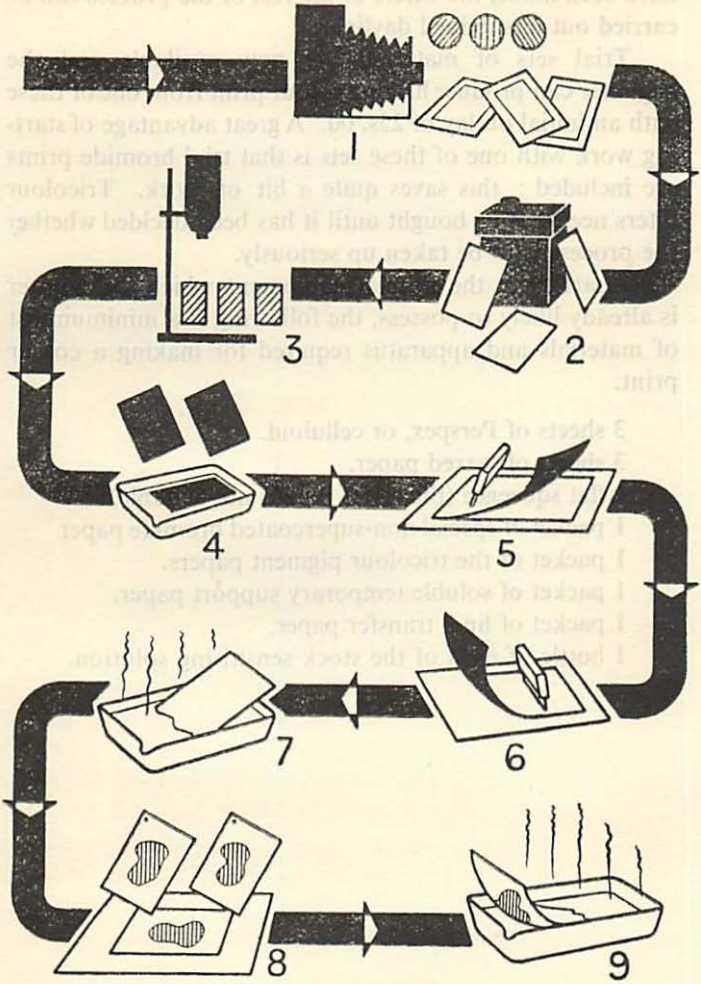
4. FINAL TRANSFER.—The print so obtained is reversed from right to left, so it is usual to make a further transfer to a final support, so that the print is the right way round.

The actual time taken to produce the finished print, assuming the bromides have already been made, will depend on whether or not the drying down operations are speeded up by artificial means. About four hours is the minimum for good quality work, but only about two hours of this can be considered as actual working time.

COST AND MATERIALS

The cost of the materials for a colour print works out at about 5s. 6d. for a whole-plate ($6\frac{1}{2} \times 8\frac{1}{2}$ in.) print, and 3s. 6d. for half-plate ($4\frac{3}{4} \times 6\frac{1}{2}$ in.), excluding the cost of the separation negatives. This is high when compared with monochrome, but if the time spent in producing it is taken into account, it may well prove the cheaper hobby.

Very little extra apparatus is required for the process and although a good darkroom is a great asset, it is perfectly possible to operate the process almost anywhere if a sink and running water are available. Once the bromide prints



Outline of the steps in the carbro process. 1. Making the separation negatives (p. 13). 2. Processing (p. 22). 3. Making the bromide prints (p. 27). 4. Sensitising the tissues (p. 55). 5. First sandwich (p. 58). 6. Second sandwich (p. 59). 7. Developing the reliefs (p. 60). 8. Registering and transfer (p. 68). 9. Final transfer (p. 74).

have been made, the whole of the rest of the process can be carried out in subdued daylight.

Trial sets of materials are now available and the beginner can produce his first colour print from one of these with an initial outlay of 25s. 0d. A great advantage of starting work with one of these sets is that trial bromide prints are included ; this saves quite a bit of work. Tricolour filters need not be bought until it has been decided whether the process is to be taken up seriously.

Apart from the normal equipment which the worker is already likely to possess, the following is a minimum list of materials and apparatus required for making a colour print.

3 sheets of Perspex, or celluloid.
3 sheets of waxed paper.
1 flat squeegee (the roller type is not suitable).
1 packet of special non-supercoated bromide paper
1 packet of the tricolour pigment papers.
1 packet of soluble temporary support paper.
1 packet of final transfer paper.
1 bottle of each of the stock sensitising solution.

SEPARATION NEGATIVES

For the first step in the colour printing process three negatives are required, taken respectively through a tricolour red, green and blue filter.

An ordinary camera is perfectly suitable for making them provided that the lens is properly corrected for chromatic aberration and so brings the image to the same point of focus with each of the filters. As three separate negatives are required, only still life can be taken with the ordinary camera, but there are many subjects which can be included in this category if the three exposures can be made in quick succession.

A simple method of speeding up the changing of filters is to mount them between two pieces of cardboard, and fit a slotted holder to the lens ; the filters can thus easily be moved across the lens after each exposure.

REPEATING BACK

This idea has been further developed in the form of a repeating back. The usual plate holder is replaced by one carrying a plate three times the normal length, with the tricolour filters which are the same size as the camera opening, mounted directly in front of the plate. After each exposure, the back is moved across, so as to bring the next filter with the corresponding part of the plate in front of the camera opening.

In the *Vivex* camera the back and shutter were connected together. After each exposure the shutter was automatically wound and the plate moved into the next

position. This type of camera was extensively used before the war for fashion plate work. The total time of exposure could be shorter than two seconds.

TRIPACK AND BIPACK

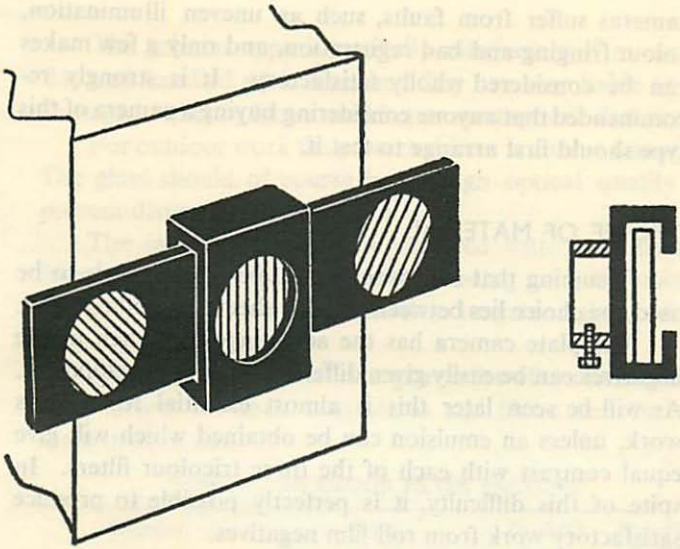
In the tripack three separate films are mounted together. The one nearest the camera lens is normally blue sensitive and requires no filter, while filters are incorporated in or between the other two. After development the three negatives are separated and used for making the colour print in the normal way. The disadvantage of the tripack is that while the first two emulsions can be mounted face to face, the third is necessarily separated from the plane of focus of the first two by the thickness of the support. It is possible to obtain satisfactory results in sizes of quarter-plate ($3\frac{1}{4} \times 4\frac{1}{4}$ in.) and over, provided that the final print is not much enlarged.

This disadvantage is not experienced with the bipack, but it needs a special camera to split the light from the lens into two beams. There is still a tendency for the first emulsion to scatter the light before it reaches the second film.

ONE-SHOT CAMERAS

A one-shot camera enables all the three negatives to be exposed at the same time. It works by splitting the beam from the lens into three parts, usually by means of mirrors or very thin semi-transparent membranes known as pellicle reflectors.

In spite of their high cost, the scope of these cameras is restricted, for owing to their construction they can be fitted only with a relatively long focus lens. In many cases it is difficult to obtain with them exposures as short as 1/25 sec. at *f*4.5, even when using the fastest plates. Many of these



Quick change filter holder. The three tricolour filters, red, green, and blue, are mounted in one continuous strip of cardboard. This moves in a special holder attached to the lens, so that any filter disc can be brought into position with the least delay. (p. 13).

or more blue. Filter factors for daylight vary with the time of day, but to a greater extent according to whether the subject is illuminated by direct sunlight or the relatively bluer sky.

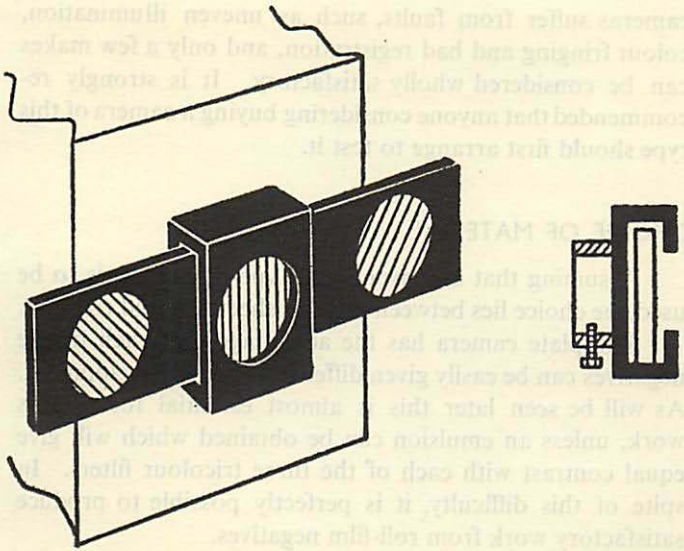
Fortunately although it is desirable to be as accurate as possible in determining the filter factors, a satisfactory print can usually be obtained, provided none of the three negatives is seriously under- or over-exposed, as the error can be corrected later on in the process. However, a test can also be made to see whether the factors chosen were correct, as soon as the negatives are developed (p. 23).

THE GREY SCALE

In order to be able to check the exposure balance of the negatives and to adjust this subsequently when making the print, the subject must contain some neutral coloured object. It is always difficult to find a sufficiently large area in a subject which is of an even neutral tone and two such areas are required before it is possible to check whether the negatives have been developed to equal contrast. So the neutral areas are usually introduced artificially in the form of a grey scale which has a number of steps ranging from white to black. The trouble is well repaid when it comes to making the print.

The grey scale in its simplest form may consist of a black and a white patch, but a few intermediate tones are desirable. A grey scale can easily be made by exposing sheets of matt surfaced bromide paper under the enlarger for varying lengths of time and finally mounting them on stiff cardboard. A piece of each of the colour pigments used in making the colour print should also be included, as this forms a good method of identifying the different filter negatives after development.

It is useful to have a number of scales of different sizes



Quick change filter holder. The three tricolour filters, red, green, and blue, are mounted in one continuous strip of cardboard. This moves in a special holder attached to the lens, so that any filter disc can be brought into position with the least delay. (p. 13).

cameras suffer from faults, such as uneven illumination, colour fringing and bad registration, and only a few makes can be considered wholly satisfactory. It is strongly recommended that anyone considering buying a camera of this type should first arrange to test it.

CHOICE OF MATERIAL

Assuming that a conventional type of camera is to be used, the choice lies between plate or sheet film and roll film.

The plate camera has the advantage that each of the negatives can be easily given different times of development. As will be seen later this is almost essential for serious work, unless an emulsion can be obtained which will give equal contrast with each of the three tricolour filters. In spite of this difficulty, it is perfectly possible to produce satisfactory work from roll-film negatives.

It has been held that film negatives are liable to stretch during processing, which is absolutely impossible with plates. However, experience has shown that this stretching is small enough to be ignored, particularly if all the films are cut from the parent roll in the same direction, and all three images oriented in the same way.

Without entering into the vexed question of negative size, it may be said that most workers would prefer something larger than 35 mm. The larger the negative size, the easier it is to work accurately. However, good colour prints from 35 mm. separation negatives *have* been made, so the enthusiastic miniaturist need not be dissuaded from using his camera for this work.

FILTERS

The tricolour taking filters can be bought either in plain gelatine or cellulose acetate sheets, or protected by glass.

The gelatine type is optically satisfactory if mounted flat and handled with care, but they are very liable to be damaged either by finger marking or atmospheric dampness.

For outdoor work the protected filter is almost essential. The glass should of course be of high optical quality to prevent distortion of the image.

The increase of exposure required with the different filters depends on the make of filter being used, the colour of light (daylight is much bluer than tungsten light) and on the film or plate used.

Most plate manufacturers give a list of recommended filter factors for their own plates and filters and enclose them in each box.

TYPICAL TRICOLOUR FILTER FACTORS

Material	*Filter*	*Daylight Factor*	*Photoflood Factor*
ILFORD			
F.P.3 film, Soft Gradation Pan plate	Ilford 204 (red)	8	3½
	Ilford 404 (green)	5½	5
	Ilford 304 (blue)	6	12
H.P.3 film	Ilford 204 (red)	4½	2½
	Ilford 404 (green)	4½	6
	Ilford 304 (blue)	5	12
H.P.3 plate	Ilford 204 (red)	4	2½
	Ilford 404 (green)	6	7
	Ilford 304 (blue)	9	15
KODAK			
P.300, P.1200, and P.1500 plates	Wratten A (red)	6	3
	Wratten B2 (green)	9	10
	Wratten C5 (blue)	7	15
Panatomic X, Plus X, and Super XX films	Wratten A (red)	7	4
	Wratten B2 (green)	6	6
	Wratten C5 (blue)	5	10

It will be noticed that with each material the green filter factor tends to remain constant whilst those of the red and blue pivot about it as the light becomes more reddish

or more blue. Filter factors for daylight vary with the time of day, but to a greater extent according to whether the subject is illuminated by direct sunlight or the relatively bluer sky.

Fortunately although it is desirable to be as accurate as possible in determining the filter factors, a satisfactory print can usually be obtained, provided none of the three negatives is seriously under- or over-exposed, as the error can be corrected later on in the process. However, a test can also be made to see whether the factors chosen were correct, as soon as the negatives are developed (p. 23).

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It is useful to have a number of scales of different sizes

ranging from a minimum of about 4 in. for close-up work, to large black and white patches suitable for more distant subjects. Such a large grey scale can be made of cloth and folded up when not in use.

When placing the grey scale in position, it is important to see that the light falling on it is similar to that illuminating the rest of the subject and that there are no coloured areas reflecting light on to it. For example if the grey scale is put perpendicular to a grass covered slope, it will almost certainly reflect a proportion of green, and be a totally false guide when used for balancing the bromide prints.

One ingenious method of producing a grey scale on the negatives is to fit a step wedge—which is nothing more than a transparent grey scale—inside the camera next to the bottom of the plate. This receives light from a piece of white cardboard which is supported just in front of the camera lens by a stay attached to the camera body. The chief disadvantage of this idea is that the camera may well be in a position where it is impossible to illuminate the white reflector with the same lighting used for the subject, e.g., when the camera is used under trees.

CHOICE OF SUBJECT

The temptation to expose on subjects with the maximum amount of colour should be resisted unless a poster effect is required. Scenes containing comparatively subdued colours are much more likely to produce satisfying results.

Large, unbroken areas of colour are always hard to deal with, particularly so if they are light in tone. Owing to the difficulty of giving perfectly even development to the negatives, and through other causes, the colour tends to wander.

Greens are sometimes difficult to render and it is usually necessary either to mask the separation negatives before

printing (p. 135) or to obtain a satisfactory rendering at the expense of the other colours.

When making direct separation negatives, the ordinary camera is limited to still-life subjects. In spite of this a number of subjects can be found even out of doors ; architecture is particularly suitable.

When working out of doors, the chief difficulties are to avoid movement of the trees or foliage and to make sure that the lighting does not change between the three exposures. If, for instance, the sky was overcast but a beam of sun appeared while exposing the red filter negative, it would be recorded as a reddish streak across the colour print.

SUBJECT CONTRAST AND LIGHTING

Unless some specific effect is wanted, different types of lighting should never be mixed. It is even possible to detect in a print the differences in colour between an old and a new photoflood bulb, as the light from the former is always a little more yellowish.

In lighting for colour, a satisfactory technique is to light as flatly as possible, filling in all shadows and then to provide modelling from one additional lamp. Unlike black and white photography colour work needs little light contrast. In colour work modelling is often provided by the variations in hue, quite independently of light and shade.

MAKING THE EXPOSURES

The three exposures may either be instantaneous ones or time exposures.

The advantage of the former is that a moment may be chosen when the conditions are just right for each exposure. There are, however, one or two snags.

In the first place shutter speeds are usually inaccurate and are not closely enough spaced to fit the different filter factors ; consequently an out-of-balance set of negatives must be accepted. An alternative is to make exposure adjustments by changing the lens stop. This is perfectly satisfactory provided that the whole of the subject is well in focus, otherwise there may be noticeable colour fringing in the print. With a focal plane shutter, where the blind travels across the face of the plate, there is a danger that its speed of travel will not be the same when exposing each of the negatives and uneven colour rendering may occur in the print. Thus it is always wise to use the maximum slit opening.

On the whole the time exposure method seems to have most to commend it. With a medium speed plate or film and a lens which will stop down to *f*32, it is nearly always possible to give exposures of not less than 5 seconds. In this way the individual exposures can be controlled more easily.

IDENTIFYING THE SEPARATION NEGATIVES

Owing to the necessity for giving different development times to the separation negatives, it will usually be desirable to identify them both before and after development. It is therefore wise to expose the negatives in the same order (red, green, blue filter) and to make a note of the plate holder or negative numbers.

Identification after development should be easy if one or more of the following methods are used :

(*a*) Inclusion of colour patches on grey scale.
(*b*) Including a distinguishing mark in the corner of the subject for each exposure, e.g., plate holders.
(*c*) Marking a corner of each plate with the letter R., G., or B. before development.

DEVELOPMENT

The aim should be to produce a set of negatives which have been evenly developed (p. 118), are of equal contrast, and have a gamma of between 0.7 and 1.0, the latter figure being applicable to negatives which are to be masked.

The term *gamma* is a sensitometric expression for the relation between negative contrast and subject contrast. It only has a meaning where the subject contrast can be measured (as in this case by the relative brightness of the black and the white of the grey scale included in the picture), as well as the negative contrast. This is done by a densitometer (p. 104). The negative must also be exposed correctly to obtain a true value for the gamma.

If the *logarithm of the exposure* is plotted against the *logarithm of the opacity* (i.e., the *density*) of the corresponding negative tones, a curve is obtained, the *characteristic curve* (p. 109). Part of this curve is a straight line, where the density is proportional to the logarithm of the exposure. The gamma is the slope of this straight line, or the tangent of the angle which this straight line makes with the log. exposure axis.

The contrast of the negative, and therefore also the gamma, increases as the time of development is increased. From the practical point of view, developing to a given gamma means developing for the time recommended by the makers of the material (and in the recommended developer) to give the required gamma.

Unfortunately, if similar development times are given to the three negatives, they very often produce unequal contrast. This defect is not always present but varies with each type of negative material. It is also affected by the developer used. This is due to the different response of the emulsion to different colours.

When a set of separation negatives is out of balance in contrast, it is possible to adjust this by :

(*a*) Intensifying one or more of the negatives (p. 24).

(*b*) Reducing the contrast of one or more of the negatives by plain masking (p. 146).

(*c*) Adjusting the contrast when making the bromide prints by using a variable contrast developer or different grades of paper (see p. 29).

(*d*) By varying the composition of the pigment sensitiser or giving different times of immersion in the No. 2 sensitising bath (see p. 43).

None of these methods can be recommended for normal practice and it is far more satisfactory to vary the times of development. Usually the blue filter negative requires about 30–50 per cent extra time.

TESTING FOR CONTRAST AND CORRECT FILTER FACTORS.—For highly accurate work there are methods of testing negative material to find both exact filter factors and development times (p. 118). The worker who does not possess a densitometer or who dislikes plotting graphs may, however, use this approximate method.

Set up a grey scale and photograph this three times, once through each of the tricolour filters. Develop the negatives for the same time and when dry make prints from each, adjusting the relative printing exposures until the lighter part of the grey scales matches in each of the prints. If a medium grade of bromide has been used the ratio of the printing exposures will give an approximate indication of the adjustment required. For example :

ADJUSTING FILTER FACTORS

	Red Filter	*Green Filter*	*Blue Filter*
Printing times required to balance lightest step of grey scale	60	80	120
Filter factors used for the test were	3	8	9
Corrected filter factors are	$3 \times \frac{80}{60} = 4$	8	$9 \times \frac{80}{120} = 6$

This method only gives correction for the relative values of the filter factors and for this reason the green filter factor is assumed correct, as its absolute value varies less than the other two.

Now inspect the darker portions of the grey scales and see if they match. If they do not, it will mean that the negatives are of unequal contrast. The alteration of the development times required to bring the negatives into balance will have to be found by trial and error, bearing in mind that the grey scales with weaker blacks are made from the negatives which require increased development.

EVEN DEVELOPMENT.—One of the difficulties in colour work is to secure even processing of the separation negatives. Any variations show themselves in the print by a tendency of the colours to wander. The best, but also most laborious way to develop evenly is with some form of brush development, but if plenty of space is allowed between the negatives and a fair degree of agitation employed, perfectly good results can be obtained even by normal methods.

If the agitation is produced by mechanical means, and is too regular, a continuous flow pattern may be set up. This will of course defeat its own object. Assuming that no special methods are available, it is probably best to agitate the developer at one-minute intervals, or better still to lift the negatives completely out of the developer for two or three seconds a number of times during development.

In the case of tank development, it is always a wise precaution to load the plates so that the same edge of the image will appear at the top of the tank for each of the three negatives.

HARMONISING CONTRAST BY INTENSIFYING

The problem of dealing with separation negatives which are not of equal gamma has already been mentioned

(p. 22). One method is to equalise the contrast by using chromium intensifier. Control is obtained by varying the acid content of the formula and where necessary by repeating the process. One great advantage of this method is that it avoids the difficulty of masking unbalanced negatives (p. 141).

Any negative which is to be intensified must have been thoroughly fixed and washed. If there is any doubt that either operation has not been thorough, it may be refixed, washed and dried. The working procedure is then as follows :

1. Soak in water for 5 minutes and then place in one of the following bleaches according to the degree of intensification required.

COMPOSITION OF CHROMIUM INTENSIFIER

Constituents	*Proportions for a Hydrochloric Acid Concentration of*			
	1 per cent	*2 per cent*	*3 per cent*	*4 per cent*
Potassium bichromate, 5 per cent solution	4 parts	4 parts	4 parts	4 parts
Hydrochloric acid, 10 per cent solution	1 part	2 parts	3 parts	4 parts
Water	5 parts	4 parts	3 parts	2 parts

The bleaching solution should be at about 65° F. (18° C.). The time of immersion must not exceed 2 minutes.

2. The negative should be taken from the bath as soon as no black silver is visible through the back. The speed of bleaching of the different baths varies as it depends on the amount of hydrochloric acid present in the solution. After bleaching :

3. Wash the negative for 2 minutes in running water.

4. Immerse in a 5 per cent solution of sodium carbonate for 2 minutes to remove the bichromate.

5. Wash for a further 5 minutes.

6. Redevelop in any M-Q developer which does not contain bromide or other silver solvent. (The pure metol developer mentioned on p. 29 can be used.)

7. Wash for 5 minutes.

8. Immerse in a 5 per cent solution of acetic acid.

9 Rewash for 5 minutes.

The gelatine is likely to be rather soft at this stage and if it is to be re-intensified, it should be dried first.

The increase in contrast produced by using the different bleaching baths or by double intensification does not appear to vary very greatly with different types of plates. The maximum intensification which can be obtained roughly corresponds to increasing a negative gamma from 0.5 to 1.0.

In order to find the degree of intensification necessary to bring the low contrast negative or negatives up to the contrast of the highest one, the required value of the intensification constant K must be calculated and the nearest in value in the table below selected.

INTENSIFICATION CONSTANTS

Hydrochloric Acid in Intensifier	*Intensification Constant K*	
	Single Intensification	*Double Intensification*
4 per cent	0.20	0.59
3 per cent	0.33	0.73
2 per cent	0.43	0.90
1 per cent	0.53	1.05

An example will make this method of working clear. Suppose the difference in density between the white and black patches of the grey scale was 0.7 in the red filter negative, 0.6 in the green and 0.5 in the blue.

The intensification constant may be found from the equation;

Required density difference = *actual density difference* + $K \times$ (*actual density difference*)

Thus for the blue filter negative $0.7 = 0.5 + 0.5$ K.

Therefore $K = \frac{0.2}{0.5} = 0.4$

For the green filter negative $0.7 = 0.6 + 0.6$ K.

Therefore $K = \frac{0.1}{0.6} = 0.17$ approx.

THE BROMIDE PRINT

A really good set of bromide prints is vital to the process and any attempt to save time in making these usually results in a wasted colour print representing some three or four hours of work.

The characteristics of a good set of bromides are :

(*a*) The prints should be balanced in contrast and density, taking into account any adjustments which may be necessary to compensate for the pigment papers being out of balance or for defects in colour rendering due to the inherent imperfections of the colour dyes.

(*b*) The contrast and density should be such as to produce the desired density and colour saturation in the final print.

(*c*) In general the prints should be of the best technical quality that can be obtained.

(*d*) The bromide paper used should be suitable.

THE BROMIDE PAPER

The normal type of paper is coated with an additional gelatine layer to prevent stress markings due to pressure during handling. This tends to inhibit the chemical action which takes place between the pigment paper and the bromide. All such paper is unsuitable for this work. Most leading makers, however, supply paper which has been specially made for the purpose.

Illingworth Carbro bromide is made in one grade of contrast only and is rather slower than the normal varieties

of bromide paper. *Kentmere* paper is made in three grades and is about four times faster ; it is particularly useful for heavy negatives where the enlarger illumination is not very powerful. *Criterion* has a rather thicker base and is intermediate in speed between the other two.

Most batches of paper vary slightly in their speed and characteristics and paper from different batches should not be used for the same set of bromides. When buying paper in packets it is as well to see that they are all of the same batch number, otherwise the last one or two sheets in a packet may be wasted.

All paper swells and stretches when wetted and the amount of stretch is greater in the direction at right angles to the fibres of the paper. The worker who buys the paper in large sizes and cuts it up himself, must make sure that each sheet used for a set of bromides is cut from the same direction, otherwise trouble will be experienced with registering the images when making the colour print. Bromide paper which has been specially prepared for one process is always cut from the same direction of the roll.

THE DEVELOPER

Most bromide developers are suitable for developing the prints, but preference is usually given to amidol or metol-hydroquinone.

NORMAL M-Q DEVELOPER

Metol	80 grains	4.5 grams
Sodium sulphite, anhydrous	1¼ ounces	31.2 grams
or crystals	2½ ounces	62.5 grams
Hydroquinone	88 grains	5 grams
Sodium carbonate, anhydrous	1 ounce	25 grams
or crystals	2¾ ounces	68 grams
Potassium bromide	40 grains	2.2 grams
Water to make	40 ounces	1,000 c.cm.

For use, 2 parts of the above stock solution are diluted with 3 parts water.

A variable contrast developer can also be used for equalising the contrast between the prints when the separation negatives are slightly out of balance. The correction possible with varying the developer composition is, however, very limited, and amounts to less than the equivalent of half a paper grade.

The variable contrast developer consists of two solutions. One of these is the stock solution of the M-Q developer given above, while the other is a hydroquinone developer.

HYDROQUINONE DEVELOPER

Sodium sulphite, anhydrous	1¼ ounces	31.2 grams
or crystals	2½ ounces	62.5 grams
Hydroquinone	320 grains	18 grams
Sodium carbonate, anhydrous	1 ounce	25 grams
or crystals	2¾ ounces	68 grams
Potassium bromide	40 grains	2.2 grams
Water to make	40 ounces	1,000 c.cm.

For normal results use the M-Q developer given on p. 28.

For increased contrast take 1 part M-Q, 1 part hydroquinone developer, and 3 parts water.

For still higher contrast take 2 parts hydroquinone developer and 3 parts water.

For soft results the metol-hydroquinone developer can be diluted. It is, however, better to use metol.

METOL DEVELOPER

Metol	150 grains	8.5 grams
Sodium sulphite, anhydrous	1¼ ounces	31.2 grams
or crystals	2½ ounces	62.5 grams
Sodium carbonate, anhydrous	1½ ounces	37.5 grams
or crystals	4 ounces	100 grams
Water to make	40 ounces	1,000 c.cm.

For use mix 1 part developer with 1 part water.

BALANCING THE GREY SCALES

The first step in making the prints is to obtain a rough estimate of the ratio of the exposures which will make the

grey scale identical in each of the prints. This can best be done by using a densitometer (see p. 104), failing that, by inspection.

A test strip is made from the grey scale of each negative in turn. These are developed together and compared, the relative exposure for the lightest part adjusted, and further sets made until the three strips appear identical when viewed in the fixing bath.

For the final tests an ultra hard grade of bromide should be used, and the strips out and overlapped when making the comparison.

If necessary, the enlarger lens should be stopped down to give exposures of not less than 60 seconds as it is difficult to time shorter periods with sufficient accuracy. With careful work it is possible to achieve a balance corresponding to plus or minus 3 seconds on 100 seconds' exposure.

If no grey scale has been included in the negative, some part of the subject which was colourless, i.e., white, grey or black, must be used for comparison purposes.

The relative exposures are then noted for when the prints are made.

BALANCING NEGATIVES OF UNEQUAL CONTRAST

If the negatives have unequal contrast, it will be found that when the lightest part of the grey scales has been matched the darker portions are not of similar density. This can best be seen when using a medium grade of paper for the test strips, as an ultra hard paper is usually too contrasty to cover the whole range of the grey scale and produces a number of similarly heavy blacks in which it is difficult to detect small variations in tone.

Adjustment of contrast between the test strips can only be made by varying the type, strength or composition of the developer (p. 29) or by using a different grade of paper.

Both these alternatives make it much more difficult to produce a balanced set of prints, and it is essential to standardise working conditions, e.g., time and temperature of development, so that the conditions under which the test strips were made can be reproduced.

When using different types of developer it is worth remembering that the reflection coefficient of the silver deposit may vary. In other words, in prints developed with different developers the same tone may correspond to different amounts of silver. Consequently the prints of equal visual density do not always produce the same effect on the pigment paper. Even if they give a correct result for the first print, they may not do so if redeveloped and used again.

Where the contrast of negatives is badly out of balance it may be easier to balance them by intensification (see p. 24), or by plain masking (see p. 146). Any of these alternatives make the production of an accurately balanced set of prints difficult, so that differential development times for the separation negatives provide a far better solution.

EXPOSURE TIMES

Having decided on the ratio of the exposures required to balance the grey scales, it still remains to determine the density and contrast to which the bromides should be printed.

The actual times of exposure may be found as in monochrome work but in colour there are three negatives, any one of which might be used as a criterion. Furthermore as the finished print is the product of the densities of all three prints, the permissible margin of error is smaller.

If a perfectly balanced set of bromides is examined, it will be seen that in over-all appearance the print from the red filter negative (cyan printer) is nearly always lightest, the

negatives occupy the same position in the enlarger. It is fairly easy to do this if one of the negatives is put in the carrier and the salient features of the enlarged image traced on the baseboard as a guide for lining up the other two.

In order to prevent the pigment frilling during development, the bromides should be masked to give a white margin at least $\frac{1}{8}$ in. wide all round. This may with advantage be increased to $\frac{1}{2}$ in. on one of the shorter sides to help in registering the bromide and pigment paper when squeegeeing them together.

The voltage of the electric main supply in some districts may at times vary as much as plus or minus 10 per cent. As these variations may take place during quite a short space of time, it may happen that the exposures which have been found to balance at the test stage will not balance the grey scales of the bromides.

There are a number of devices on the market which may be connected to an alternating current mains supply and will maintain a reasonably constant voltage output. However, they are apt to be rather expensive.

The simplest and cheapest device is a transformer wound with a saturated primary. This can be made to the required specification by any firm specialising in the type of work, at a cost of about 40s. 0d.

When stating the requirements, it is important to remember that a small variation of the voltage to the enlarger bulb will have far more than a proportional effect on the illumination. For example, if the variation in light output of the enlarger bulb is not to exceed 2 per cent either way, the voltage must be controlled within about 0.5–1 per cent. A typical specification for the transformer would be :

Nominal mains voltage	230 *volts*
Output	100 *watts at* 230 *volts*
Maximum permissible variation in output voltage	*plus or minus* 0.5 *per cent with mains voltage variation of plus or minus* 10 *per cent*

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It is important to remember that this type of stabilising

device will not be effective if the frequency of the grid system is changing, and work must be stopped if power cuts are likely to occur.

A possible alternative which may appeal to some workers is the use of a voltmeter and rheostat. The snag here is the added complication of adjusting a rheostat while making the exposures, and the high cost of a voltmeter which will measure accurately to less than 1 per cent.

DEVELOPING THE BROMIDES

Development of the bromides follows the normal procedure. Each print must normally receive precisely similar treatment.

Ideally the conditions should be standardised so that it is possible to repeat them if another set of prints is made. This is particularly important when adjustments in contrast have been made with a variable contrast developer.

The chief variables are the composition, temperature and degree of exhaustion of the developer, and time of development. The effects of developer exhaustion may be avoided by using a very large quantity of developer, developing the three prints at the same time together, or by dividing the developer into three equal portions, so as to have fresh solution for each print. For the amateur the latter is likely to be the most economical method.

FIXING AND WASHING

The only point to note about fixing the bromides is to avoid the use of a formula containing a hardener such as alum. Any hardening of the prints tends to prevent the chemical reactions from taking place between the bromide and pigment paper.

Although washing should always be thorough, prolonged soaking must be avoided and the quicker the hypo can be eliminated the better.

In many districts the tap water contains lime or iron. Both these substances are absorbed by the bromides and tend to cause loss of highlights in the colour print, and in extreme cases will prevent the bromides bleaching.

It is nearly always worth while giving the prints an acid rinse by immersing them for 2 minutes in a 2 per cent solution of acetic or hydrochloric acid and swabbing the surface with cotton wool. This treatment may be given either at the end of the first washing and before drying, or just before the prints are required for use. If the prints are dry, they must be re-soaked in water for a few minutes as otherwise they tend to absorb too much acid.

The amount of acid retained has a very marked effect in decreasing the density and contrast of the colour print, consequently the bromides must be washed in running water for 10–15 minutes after the treatment. If this washing is prolonged, the lime is re-absorbed and if too short, too much acid will be retained. Further it is important that washing should be even and the prints not allowed to stick together.

Although the prints may be used immediately after the fixing and washing, it is an advantage to let them dry, as it is then possible to remove any dark spots, etc., with a razor blade.

LOCAL CONTROL ON THE BROMIDE PRINTS

LOCAL CONTROL OF DENSITY.—When making black and white prints, local control by shading or holding back areas during enlarging is a comparatively simple matter. In the case of colour work, however, there are three prints to be considered, and unless each print is given similar treatment, a change of colour will result.

So areas shaded or held back must be identical and the time of control must be in the same proportion to the exposures given to each print. For example, if the exposures

needed to balance the bromides are 60, 100, and 80 secs. and a 20 per cent decrease in density is required in some area, the times of shading will be 12, 20 and 16 secs. respectively.

There are three methods of varying the amount of light reaching different parts of the bromide paper:

(*a*) Controlling the light between the enlarger lens and the bromide paper.
(*b*) Altering the effective density of the negative.
(*c*) Varying the light between the enlarger bulb and condenser.

The first method (*a*) must be used with discretion and only experience can tell the maximum degree of control which can safely be applied in this way.

Areas with complicated outlines should never be shaded by hand. The best method is to do this, as in combination printing, by cutting out a mask and supporting it on a sheet of glass a little distance away from the bromide paper.

The second method (*b*) needs some knowledge of retouching, and unless the worker has this already, it is better not to try.

For increasing density one or more coats of some semi-opaque medium may be applied selectively to the back of the negative or to a mask. If, on the other hand, some portion of the negative needs printing up, the whole area is treated and the medium scraped off the parts which are to be lightened.

Alternatively the work can be carried out on a mask. The advantage of this is that there is no danger of colour fringing, provided that the mask can be accurately registered with each of the three negatives in turn. The simplest way of registering a mask is to sacrifice the outside edges of the subject and to trace salient details on the mask. The snag is that since there may be two thicknesses of glass between the negative image and the mask trace, it is hard to avoid parallax errors. This can be overcome if the mask is made on sensitive material. The centre of one of the separation negatives is covered over and the outside registration detail printed on to the mask by contact. After the necessary hand work has been carried out on the back of the mask,

it is registered with the marginal image in contact with that of the separation negative. When printing from this combination, the mask ought to be next to the enlarger condenser, consequently the subject will be reversed from right to left. This may be corrected later in the process by transferring the reliefs direct to a final support (single transfer p. 77).

The third method (*c*) is only suitable for dealing with large areas, but is almost foolproof. The only precaution which must be taken is to make sure that each of the separation negatives is put in the same position in the enlarger. In effect the method consists of producing uneven illumination of the enlarger baseboard by shading on a diffusion screen fitted between the enlarger lamp and condenser. As this screen is completely out of focus all that is necessary is to draw a number of pencil shading lines on the ground glass. Experiment with a few small pieces of sticking plaster will quickly show which areas must be treated to produce the required effect. The side shaded should be the opposite to that of the image on the baseboard.

MODIFICATION OF COLOUR RENDERING.—This is generally much easier than density control, as only one or at the most two of the negatives will need treatment. Either of the first two methods described on p. 37 can be used. For very small areas, pencil work on the emulsion side of the negative is often a useful alternative to applying washes of colour on the finished print.

MATERIALS AND TOOLS

Before starting to make the colour print itself, it is necessary to decide which of the possible alternative materials and working techniques are to be used. In this chapter the advantages and disadvantages of each are considered.

The worker who is new to the process may find it helpful to study a working chart (p. 50) before reading this chapter, and may omit those sections dealing with the single bath sensitiser.

THE PIGMENT PAPER

Unfortunately suitable dyes for the tricolour pigments depart to a great extent from the ideal colours which would be required for perfect colour reproduction. The pigments used represent varying forms of compromises.

Two kinds of *Autotype* pigment for the trichrome carbro pigment papers are at present available. These are known respectively as *Series* 2 and *Series* 3 pigment.

In Series 3, the light fastness of the pigments is to a certain extent sacrificed in order to obtain more satisfactory colour rendering. Normally a colour print in Series 3 pigments is likely to show signs of fading of the magenta and to a lesser extent cyan if exposed to daylight in the average room for more than 2 months, but it will keep indefinitely in an album.

Series 2 pigments have far better lasting properties, but if good reproduction of several colours is required, masking must be employed ; the pigments are also less transparent

and the colours will not be quite so brilliant as with Series 3.

Whether the pigment paper or tissue is bought in the roll or in packets cut to size, it is advisable to get enough of the same batch to last for 6 months' work, as the characteristics of each batch are apt to vary slightly. It is no economy to waste several prints in finding out the percentage alterations which must be made to the exposures of the bromides in order to compensate for variations in the pigment paper. Provided that storage conditions are satisfactory, pigment paper should remain in good condition for about a year. It is particularly important to avoid formalin fumes, as these will render the gelatine insoluble.

A simple test to find out if the pigment paper is still usable is to immerse a small strip in warm water (about 105° F.) and see if the gelatine dissolves easily.

TRANSPARENT SUPPORTS

Until recently celluloid was used exclusively for the transparent supports.

The surface of a support must be such that the relief image will adhere to it during development yet leave it on transfer to the soluble temporary support. In order to achieve this the celluloids have to be slightly waxed, which adds perhaps three-quarters of an hour's work to the process. Apart from the initial waxing and polishing, some wax adheres to the pigment image and must be removed from each relief after transfer to the soluble temporary support.

The answer to the problem is the use of one of the modern plastics. Perspex, Co-polymer (of vinyl acetate and vinyl chloride) and ethyl cellulose are suitable. The support should be at least 1 in. larger all round than the size of the pigment paper and the following thicknesses are recommended :

0.08 in. or 2 mm. for prints 10 × 12 in. or over.
0.04 in. or 1 mm. for prints under 10 × 12 in. but over 6 × 8 in.
0.02 in. or 0.5 mm. for prints 6 × 8 in. and under.

Perspex is difficult to obtain in thin sheets, and thicker sizes may be used. The disadvantage is that the support cannot easily be bent if this is necessary to help in registering the colour reliefs. There is also a possibility that if the soluble temporary support is dried down very rapidly, excessive stretch will occur as the support will be too strong to bend in sympathy.

This type of plastic material cannot be cut with scissors and has either to be sawn with a small toothed saw (a fine hacksaw blade is satisfactory) or dealt with in the same way as glass.

New Perspex should always be given an initial polishing with liquid metal polish. If the surface becomes badly contaminated with grease the treatment may be repeated. The metal polish must be very thoroughly rubbed off ; if any trace remains the surface of the support becomes more adhesive and the relief image may refuse to transfer to the soluble temporary support.

For normal cleaning after use, a rub over with petrol lighter fuel is all that is required.

It is most important not to scratch the surface, as this will also tend to prevent the relief stripping. For this reason it is best to use only one face of the support. A simple way of ensuring that this side is uppermost is to round off one of the corners and always to keep this at the top right-hand side when working.

WAXING CELLULOID SUPPORTS

Although the use of a Perspex type support is strongly recommended, this may not always be easy to obtain. The

procedure for waxing celluloids is therefore worth noting.

Wax can be applied in a solution of petrol or preferably turpentine, and is available ready prepared under the name of *Autotype Waxing Solution.* If the worker prefers to mix his own solution he should take 5 grains (0.3 grams) of *Autotype Trichrome Waxing Compound* and dissolve this in 5 ounces (140 c.cm.) of petrol or lighter fuel.

The waxing solution is sprinkled on to the celluloid, rubbed over the whole surface and then polished very thoroughly with a clean soft cloth. Provided the initial waxing has been thorough it is virtually impossible to remove too much of the wax by polishing, but if any excess remains the relief image is likely to frill and come away from the support during development. Some makes of motor car body polish (e.g., *Karpol* and *Lifeguard*) can be used for the dual purpose of cleaning and waxing the supports.

To avoid the danger of accidentally using the unwaxed side of the celluloid it should be marked in the same way as was recommended for the Perspex support.

After use the celluloids may be cleaned with lighter fuel. This does not completely remove all staining and metal polish may be used occasionally.

Methylated spirits dissolves celluloid and should never be used.

THE SENSITISER

There are a number of published formulae for pigment sensitising baths. They fall into two main groups ; those employing a single bath and those in which the pigment is immersed in two separate solutions.

The two bath method is usually recommended for those starting the process and has the following advantages :

(*a*) Control of contrast is simple as it depends on the time of immersion in the No. 2 bath.
(*b*) No special apparatus is required for bringing the pigment paper and bromide into contact.
(*c*) The results are rather brighter and, some workers consider, of better quality than can be obtained with single bath sensitiser.

Unfortunately the effective time of immersion in the No. 2 bath, which includes the time taken in bringing the bromide and pigment paper into contact, is very short and varies from 15 to 45 seconds according to the degree of contrast required. This makes it difficult to work in sizes much above whole-plate and it is not always easy to give exactly similar treatment to each of the three colours.

The single bath sensitiser has the characteristic that bleaching action on the bromide takes place immediately the pigment paper and bromide touch. Unless some mechanical means such as a wringer is used for bringing the two together, there is a danger of losing highlight detail and causing colour to wander in the lighter parts of the print. Control of contrast is obtained by altering the composition of the bath and not by varying the time of immersion. The chief advantages of the single bath sensitiser are:

(*a*) The sensitising procedure can be completely standardised.
(*b*) It is easy to work with the larger sizes of print.
(*c*) If a squeegee blanket is used all three colours can easily be sensitised and squeegeed to the bromides at the same time. This ensures that each colour will receive precisely similar treatment and also saves quite a lot of time.

It is suggested that the beginner should start by using a two-bath sensitiser and if necessary change over to the single bath when he decides to work in the larger sizes.

As every sensitiser has its own characteristics, the worker should avoid the temptation of trying out alternatives until he has thoroughly mastered the process and is convinced that the new formula will produce some worthwhile advantage.

TWO-BATH SENSITISER

Stock Solution A		
Potassium ferricyanide	2 ounces	50 grams
Potassium bromide	2 ounces	50 grams
Distilled water to make	20 ounces	500 c.cm.
Stock Solution B		
Potassium bichromate	360 grains	20 grams
Chromic acid	80 grains	4.5 grams
Chrome alum	200 grains	11 grams
Distilled water to make	20 ounces	500 c.cm.

The working baths are made up as follows :

No. 1 Working Bath	
Stock Solution A	1 part
Water	4 parts
No. 2 Working Bath	
Stock Solution B	1 part
Water	4 parts

This formula is *not* the same as that used for monochrome carbro but the stock solutions may also be bought ready made up.

The No. 1 working bath can be re-used a number of times until it discolours. The effect of passing pigment paper through the No. 2 bath is to reduce the chromic acid content and this will tend to give progressively darker images. In order to get standardised results and maintain correct colour balance between the three pigment images a minimum of about 15 ounces (380 c.cm.) of solution should be used for a set of whole-plate prints, or fresh solution used for each colour.

There are a large number of other published formulae. With each it is important to make tests for the type and density of bromide print to be used. Different sensitisers may need bromide prints of different density.

SINGLE BATH SENSITISER

Solution No. 1

Potassium bichromate	1 ounce	25	grams
Potassium ferricyanide	1 ounce	25	grams
Potassium bromide	1 ounce	25	grams
Distilled water to make	20 ounces	500	c.cm.

Solution No. 2

Glacial acetic acid	1 ounce	25	c.cm.
Hydrochloric acid (pure)	1 ounce	25	c.cm.
Formaldehyde, 40 per cent	22 ounces	550	c.cm.

Solution No. 3

4 per cent solution of pure hydrochloric acid in water

The working bath is made up as follows :

No. 1 solution	1 ounce	25	c.cm.
No. 2 solution	1 dram	3.1	c.cm.
Distilled water	7 ounces	175	c.cm.
No. 3 solution	¼–2½ drams	1–8	c.cm.

The No. 3 solution provides a method of controlling contrast. The more acid is added the softer the results obtained.

The performance of the sensitiser is affected by its degree of acidity, which can be stated in technical terms by a pH value. The most common causes of variations are due to the quality and age of the chemicals used in making the stock solution (formalin is particularly liable to deterioration), and to a lesser extent the acidity and impurities of the water used in mixing the working solutions. As a pH meter is a very expensive instrument, such variations as may occur must be accepted. But it is well worth while to buy the best quality chemicals, and to use distilled water for making up the stock solutions.

With the single bath sensitiser it is absolutely essential to maintain the same ratio of sensitiser to pigment paper area, and to use fresh solution for each sheet of pigment paper.

This also applies to a lesser extent to the two bath sensitiser, but the first bath may be re-used. It was previously thought that the variations which occurred were due to solution being carried over from the first bath but this view has been proved incorrect.

The stock solution No. 1 will keep almost indefinitely in the dark. In cold weather it deposits crystals of bichromate but these can easily be dissolved by warming and shaking.

The No. 2 solution produces a white deposit almost immediately after mixing. This has very little effect on its working properties but only the clear liquid from the top of the bottle should be used. The working bath will not keep for more than a few hours after mixing. This is no disadvantage for the amateur as with this type of sensitiser it is vital to maintain a constant ratio between quantity of sensitiser and pigment area, and unless all three colours are sensitised at the same time, fresh solution must be used for each piece of pigment paper.

OTHER SENSITISERS

While in my opinion the formula quoted above can produce results equal to most other single bath sensitisers, it may be useful to mention the formula with was developed by Colour Photographs Ltd., and used in their Vivex process, as it is in use by many commercial firms to-day.

SINGLE-BATH SENSITISER

Chromic acid	32 grains	1.8 grams
Potassium bromide	175 grains	10 grams
Potassium ferricyanide	175 grains	10 grams
Chrome alum	88 grains	5 grams
Water to make	40 ounces	1,000 c.c.

When mixed it will keep in good condition for about a week, after which it produces fog. This may be avoided by making up two stock solutions, one which chromic acid only, and mixing before use.

The temperature limits are between 50° and 70°F. and the time for sensitising can be varied between 5 and 15 minutes, the longer period giving a rather lighter image.

As with all single bath sensitisers, the ratio between amount of sensitiser and pigment area is important. Increasing the volume from 4 to 10 c.cm. per square inch of tissue surface results in a progressive decrease in contrast and density.

The bath can be replenished by adding approximately 25 c.cm. of 3.6 per cent solution of chromic acid to every 1,000 c.cm. of used solution. In this way it is possible to use the sensitiser up to ten times over.

The composition of the sensitiser is not very critical, the chromic acid can be varied between 1 and 2.5 grams, and the more is used the quicker the print is bleached, but the lighter it will be. The potassium bromide can be increased up to 40 grams ; this increases the contrast, while a reduction in the ferricyanide to a minimum of 5 grams will lower the contrast. Once a working formula has been established it is not advisable to control contrast by any important alteration in the sensitiser, as the colour balance will be affected.

The secret of success does not lie so much in the sensitiser formula as in finding out exactly what is required to suit the sensitiser characteristics, for instance the best contrast and density to which the bromides should be printed.

A hardening chemical such as chrome alum or formalin is included in the formula to prevent excessive swelling of the pigment images and to strengthen them.

When testing out a new sensitiser the most common troubles which an unsatisfactory formula is likely to produce are :—

(*a*) Poor tone reproduction. The densities of the pigment should be proportional to those of the parent bromides—this can easily be checked by making step wedges in each of the pigments and superimposing them. It must be possible to produce a good grey in all densities.
(*b*) Failure to retain highlight detail.
(*c*) Degraded whites or veiling of the whole print.
(*d*) A tendency for mottle, or colour wander.
(*e*) Difficulties in processing operations, e.g., frilling or excessive softening of the gelatine.

SQUEEGEEING APPARATUS

As mentioned previously, the single-bath sensitiser is difficult to operate satisfactorily without some mechanical

means of bringing the bromide and pigment paper into firm contact as soon as the two meet.

A photographic or domestic wringer with rubber rollers is normally used for this purpose. It is important to see that it works smoothly. If the two rollers are both driven it is generally advisable to remove one of the connecting gear wheels, so that the two rollers work in step.

Before feeding the bromide print and pigment paper into the wringer they should each be mounted on a flexible support. The supports or squeegee blanket can be made from sheets of celluloid or other plastic material. Guide marks should be drawn on the supports for positioning the bromide and the pigment paper, for easier registering.

The wringer may be set up so that the blanket is fed into the rollers either vertically or horizontally. When working in the horizontal position the lower support should be the thicker to make it self-supporting ; about 0.06 in. (or 1.5 mm.) is suitable. The upper support must be really flexible as it is held at an angle to the other to prevent the pigment and bromide touching before reaching the rollers.

In order that the two ends of the squeegee blanket may be easily brought together, they can be permanently hinged with adhesive tape.

The pressure between the rollers should not be excessive, but must be sufficient to produce good contact between the bromides and pigment paper.

If there is enough working space, all three colours can be squeegeed to their respective bromides at the same time. This takes a squeegee blanket about four times as long as the width of the print being made, and it will need to be supported on a table both before and after passing through the wringer. With this method all three pigment colours must be sensitised and developed together. This saves time and ensures that each relief receives precisely similar treatment ; but it needs a large developing dish.

PREPARATIONS

THE TIMETABLE

Before making the colour reliefs (p. 55) it is essential to work out a programme so that each of the three images will receive similar treatment (see also p. 117).

When working in larger sizes, say 10 × 12 in. or over, the time allowed for sensitising and combining the bromide and pigment paper is rather too short, and a modified programme can be followed.

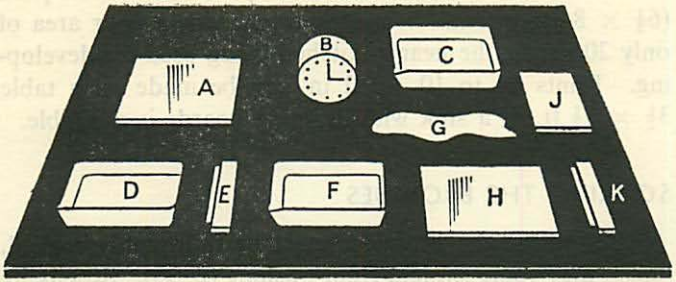
A possible alternative is to complete the operations up to and including development on each colour separately. The period of contact between the pigment paper and bromide may be shortened to about 7 minutes ; if much less than this is given the chemical action may not proceed to finality and timing becomes critical.

LAYOUT OF WORK BENCH

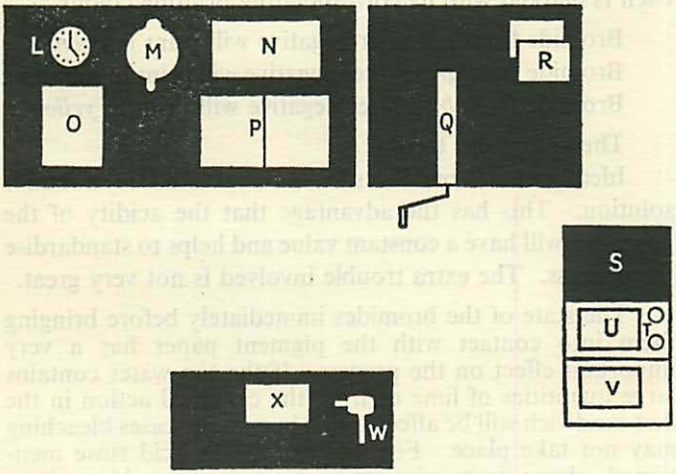
The purpose of a sensible layout is to make sure that everything is handy just when and where it is needed. The best way is to arrange the items from left to right in the order in which the various steps of the working procedure will follow. That is, we start with the soaking bath for the bromides, and go on via the sensitising baths, squeegeeing plate and squeegee (or the squeegee blanket and wringer for the single-bath process) to the developing baths, and drying table. The worker will have to adapt the details to suit his own conditions, but the layouts on p. 51 may serve as a guide in deciding how to allot the available space.

Although an ideal layout would require a fair sized

Time on Clock (Minutes)		*Operation*	*Time Taken (Minutes)*	
Small Prints	*Large Prints*		*Small Prints*	*Large Prints*
0	0	Sensitise cyan tissue (p. 56)	3	3½
3	3½	Squeegee into contact with red-filter bromide and put sandwich between greaseproof paper (p. 58)	2	3½
5	7	Sensitise magenta tissue (p. 59)	3	3½
8	10½	Squeegee into contact with green-filter bromide and put sandwich between greaseproof paper (p. 58)	2	3½
10	14	Sensitise yellow tissue (p. 59)	3	3½
13	17½	Squeegee into contact with blue-filter bromide and put sandwich between greaseproof paper (p. 58)	2	3½
15	21	Clear up work table	3	3
18	24	Separate cyan tissue from bromide print and squeegee on to its transparent support (p. 59) (including spare time)	5	7
23	31	Separate magenta tissue from bromide print and squeegee on to its transparent support (including spare time (p. 59)	5	7
28	38	Separate yellow tissue from bromide print and squeegee on to its transparent support, then get ready for development (p. 59)	7	7
35	45	Develop cyan tissue (p. 60)	5	7
40	52	Develop magenta tissue (p. 60)	5	7
45	59	Develop yellow tissue (p. 60)	5	7
		Total	50	66



Bench layout for starting work with the two-bath process. A and H, Sheets of glass. B Clock. C Water for soaking the bromide prints. D No. 1 sensitiser. E Squeegee. F No. 2 sensitiser. G Cloth to dry second squeegee K, which is used only to squeegee pigment paper and bromide print together. J Waxed paper and blotting paper.



General layout of working room for single-bath process. L Clock. M Graduated jug with sensitiser. N Water for soaking the bromide prints. O Sensitising dish. P Squeegee blanket. Q Wringer. R Blotting paper, waxed paper, and transparent supports ready at hand. S Space for putting sandwiches. T Sink. U Developing dish with hot water. V Dish of cold water. W Hair dryer or similar drying aid. X Pigment papers at hand before use.

room, the writer has frequently made whole-plate ($6\frac{1}{2} \times 8\frac{1}{2}$ in.) prints in a dark room with a floor area of only 20 sq. ft., the nearby kitchen being used for developing. Prints up to 10 × 12 in. can be made on a table $3\frac{1}{2} \times 2\frac{1}{2}$ ft., if a sink with draining boards is available.

SOAKING THE BROMIDES

Before use the bromides must be thoroughly soaked, unless they come straight from washing (p. 36). Resoaking must always be sufficient to allow the paper to expand fully (about 10 minutes), as otherwise the gelatine reliefs may not register accurately, giving blurred outlines and colour fringes.

Examine the three bromide prints to make sure that each is marked with its corresponding printing colour :

Bromide from *red* filter negative will print in *cyan.*
Bromide from *green* filter negative will print in *magenta.*
Bromide from *blue* filter negative will print in *yellow.*

Then put them to soak.

Ideally the bromides should be soaked in a buffer solution. This has the advantage that the acidity of the bromides will have a constant value and helps to standardise the process. The extra trouble involved is not very great.

The state of the bromides immediately before bringing them into contact with the pigment paper has a very important effect on the process. If the tap water contains large quantities of lime or iron, the chemical action in the first sandwich will be affected and in extreme cases bleaching may not take place. For this reason the acid rinse mentioned above is a wise precaution, and washing times should never be excessive.

The chief variable introduced is the degree of acidity of the bromides, which will depend on the amount of washing after giving an acid rinse, and on the characteristics of the tap water.

Standardisation may be obtained by soaking the bromides in a buffer solution immediately before use. A buffer solution is usually composed of two chemicals, one acid and the other alkaline, and has the property of maintaining a fixed pH value, even with small additions of acid or alkali.

A number of chemicals can be used for this purpose, but any buffer solution containing citric acid must not be used as it will cause loss of highlights, loss of sharpness in the shadows, and the end point of development of the colour relief tends to be undefined.

The following formula is recommended :

Solution A.—23.88 grams of di-sodium hydrogen phosphate (Na_2, HPO_4, $12H_2O$) in 1000 c.cm. of water.

Solution B.—9.08 grams potassium di-hydrogen phosphate (KH_2 PO_4) in 1000 c.cm. of water.

For use, take 12.3 c.cm. of solution A and 25 c.cm. of solution B. This produces a pH of 6.5. The mixture may be diluted to 50 c.cm. without change of pH.

The pH scale measures acidity or alkalinity of a solution on a logarithmic basis, over 7 being alkaline and below that figure acid. Solution A. in the above formula has a pH of 9.2 and solution B. of 4.5. By altering the amounts of these stock solutions, different pH values may be obtained. In general the effect of lowering the pH value of the buffer solution is to produce a lighter print with slightly less contrast. It is interesting to note that whereas the addition of extra acid to the single bath sensitiser (p. 45) chiefly affects contrast and to a lesser degree density, lowering the pH value of the buffer solution primarily affects density.

The actual decrease in density produced by varying the pH value between 6.5 to 4.5 is not great and the most noticeable change occurs at the low pH values, say between 5.5 and 4.5. Unfortunately, as the pH goes below 5.5, the single bath sensitiser becomes very sensitive to small increases of acid, and control of contrast by this method is difficult. It is strongly recommended that once a pH value is chosen for the buffer solution, no attempt should be made to obtain changes in density of prints by varying it. The actual value chosen is not of great importance. With a low pH of say 5.5 it is probably sufficient to give the bromides

a thorough swabbing in the buffer solution and to omit the acid rinse.

For the benefit of those who want to experiment, the table below gives a list of approximate pH values obtained by mixing different quantities of solutions A and B.

BUFFER SOLUTIONS

Solution B (Acid) c.cm.	*Solution A (Alkali)* c.cm.	*pH Value*
25	0.0	4.5
25	0.3	5.0
25	0.6	5.3
25	1.7	5.7
25	2.2	5.8
25	3.6	6.0
25	4.5	6.1
25	6.1	6.2
25	7.3	6.3
25	9.2	6.4
25	12.3	6.5
25	15.0	6.6
25	19.2	6.7
25	24.2	6.8

As these chemicals, particularly the acid, are liable to vary, these figures must only be treated as approximate.

It must be emphasised that the water or buffer solution in which bromides are soaked before use must *never* be alkaline and consequently a pH value of over 7 is inacceptable. When working with a pH only just below the neutral point, it is worth while making an initial test with blue litmus paper to confirm that the bath is in fact acid.

MAKING THE COLOUR RELIEFS

The complete process of making the colour print can be divided into three stages. As a break can be made between each stage, they are described separately.

The first stage is making the colour reliefs. It consists of :

1. Sensitising the tissue.

2. Squeegeeing bromide and tissue together to make the first sandwich.

3. Transferring the tissue to the transparent support to make the second sandwich.

4. Developing and drying the colour reliefs.

5. Trial registration.

Lay out the work bench (p. 51), polish the transparent supports (p. 41), and get the tissues ready. If the paper is in rolls, cut each colour from the roll in the same direction, and at least $\frac{1}{2}$ in. longer each way than the bromides. See that the bromides are sufficiently soaked (p. 52).

PREPARING THE TWO BATH SENSITISER

The working baths for sensitising should now be prepared. It will be found that 8 ounces (240 c.cm.) is about the minimum quantity of solution for the No. 1 bath when working in whole-plate size. As the No. 2 bath is affected by passing pigment through it, at least 15 ounces (450 c.cm.) will be needed. Alternatively fresh solution should be used for each colour.

The ideal temperature for the solutions is between 58° and 63° F. (14–17° C.). Although it is possible to work with

temperatures as high as 70° F. (21° C.), the gelatine becomes very soft. Some allowance must also be made for the increase in density and contrast which occurs at higher temperatures.

SENSITISING THE TISSUE

When everything is ready, note the time and then push the cyan pigment paper face downwards into the No. 1 bath. As soon as both surfaces have been wetted, turn it face upwards and remove any air bells which cling to the surface with the finger tips.

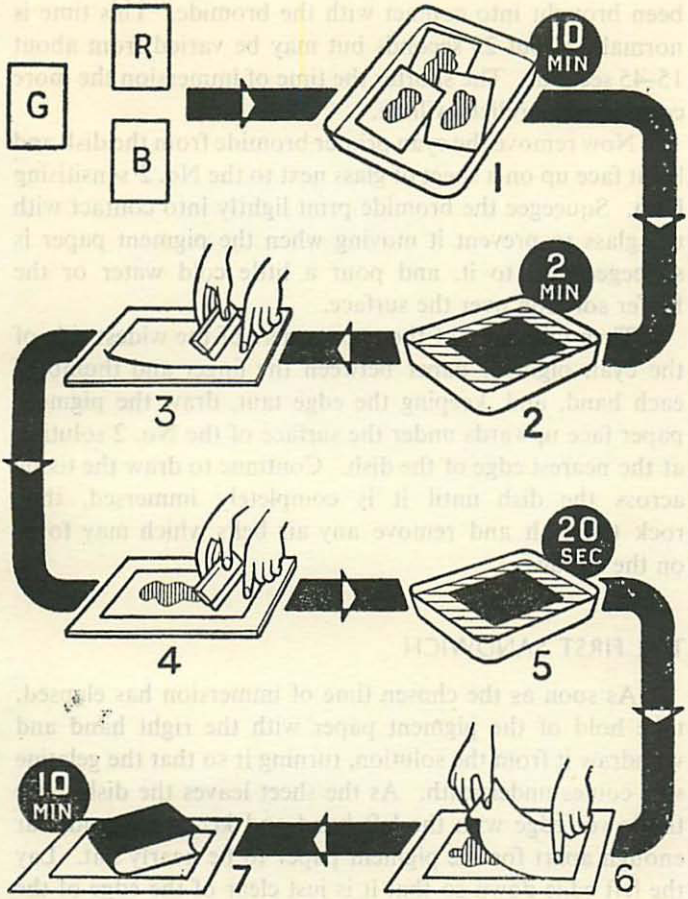
During sensitising, the pigment paper should be turned over several times and the dish rocked to ensure even action. The exact procedure adopted depends on the condition of the pigment paper, which is always difficult to handle if it is very dry or has been taken into a warm atmosphere some time before use.

After about 2 minutes the tissue should be taken out of the bath, laid face down on a clean sheet of glass, and the surplus solution squeegeed from it. The object of this procedure is to allow the next sensitising bath to act evenly on the pigment surface.

The temperature of the sheets of glass must be the same or lower than that of the solutions, as otherwise the tissue is liable to stick. In hot weather the glass may be cooled by placing in iced or cold tap water.

Provided that the workroom temperature is not much over 60° F. (15° C.) it is possible to process all three colours in this way and after stripping them from the glass to hang them on clips until the next stage of the process.

The No. 2 bath is a control bath. The time of immersion is very critical as it controls the contrast of the relief image. The effective immersion period includes the time taken after the tissue has been removed from the bath and before it has



Sensitising and first sandwich with the two-bath process. 1 Soak the bromide prints from the red, green and blue filter negatives for 10 min. 2 Immerse cyan tissue in No. 1 bath for 2 min. 3 Squeegee tissue face down on to sheet of glass. 4 Lightly squeegee red filter bromide print face up on to another sheet of glass. 5 Immerse tissue in No. 2 bath for 20 sec. (can be varied, p. 56). 6 Bring tissue in contact with bromide print, and squeegee. 7 Put between sheets of waxed paper under *slight* pressure for 10 min. Repeat from step 2 with magenta and yellow tissues.

been brought into contact with the bromide. This time is normally about 25 seconds but may be varied from about 15–45 seconds. The shorter the time of immersion the more contrasty the reliefs will be.

Now remove the cyan printer bromide from the dish and lay it face up on a sheet of glass next to the No. 2 sensitising bath. Squeegee the bromide print lightly into contact with the glass to prevent it moving when the pigment paper is squeegeed on to it, and pour a little cold water or the buffer solution over the surface.

Then take hold of the two corners of the widest side of the cyan pigment paper between the finger and thumb of each hand, and, keeping the edge taut, draw the pigment paper face upwards under the surface of the No. 2 solution at the nearest edge of the dish. Continue to draw the tissue across the dish until it is completely immersed, then rock the dish and remove any air bells which may form on the surface.

THE FIRST SANDWICH

As soon as the chosen time of immersion has elapsed, take hold of the pigment paper with the right hand and withdraw it from the solution, turning it so that the gelatine side comes underneath. As the sheet leaves the dish, seize the lower edge with the left hand and keep the hands far enough apart for the pigment paper to be nearly flat. Lay the left edge down so that it is just clear of the edge of the bromide print and hold it down firmly on the glass by pressing with the finger and thumb of the left hand (p. 57, No. 6). Let the rest of the pigment paper fall lightly upon the bromide print.

Now grasp the flat bladed squeegee with the right hand and make two firm sweeps from close against the left finger and thumb towards the right, then repeat from right to left.

The squeegeeing pressure applied should be sufficiently firm to eliminate most of the moisture from the sandwich. It will be found helpful to dab the squeegee on a folded cloth between the strokes, so that the blade can get a grip on the back of the pigment paper.

The chemical action between the pigment paper and bromide begins as soon as the two meet, consequently delay in starting to squeegee may cause loss of highlights. Any movement during the latter part of the squeegeeing is liable to produce a double image. With a little practice the total time taken in performing this operation should not exceed 5 seconds.

After the sandwich has been completed it should be removed from the glass with a pallette knife, blotted evenly to remove surplus moisture and put between sheets of grease-proof paper in a cool place with a book on top of it. It should not be exposed to bright light as the pigment paper is now light sensitive.

Similar treatment is next given to the magenta and yellow pigment papers after which the No. 1 bath can be poured into a bottle for future use and the No. 2 bath thrown away.

One of these dishes should be rinsed out and filled with water, as it will be required for the next stage of the process.

THE SECOND SANDWICH

When the cyan sandwich has been left for 10 minutes, the cyan pigment paper is stripped from the bromide print and floated face downwards on the surface of a dish of cold water.

A transparent support is then slid underneath it and the two brought into contact under water.

Now the two are removed together and squeegeed firmly into contact.

Examine the back of the support to see if any air bubbles have been included.

It is then blotted to remove all surplus moisture, covered with a sheet of greaseproof paper and laid aside with a book on top of it.

The bromide print which was bleached during the first sandwich should be put in a dish of cold water preparatory to washing.

The same procedure is repeated for each of the other two colours.

If the tissue and bromide sandwich is difficult to separate, it is due to either the gelatine becoming too soft or the sandwich drying down too much.

When the working temperatures are very high, reduce the time in the No. 1 sensitising bath to about 1½ minutes and keep the sandwich as cool as possible.

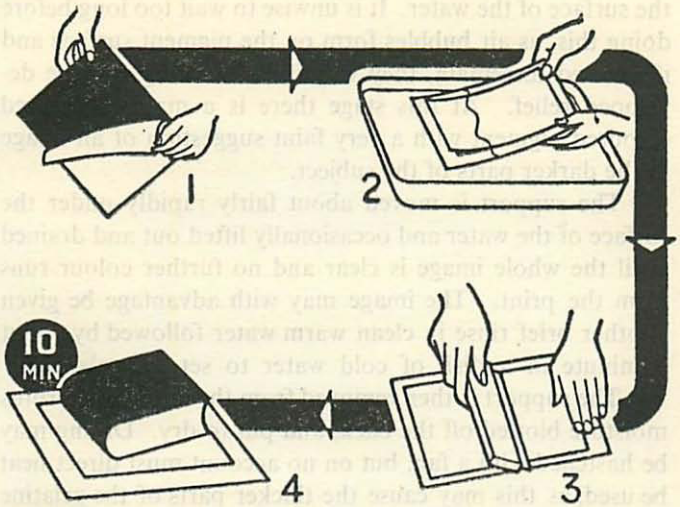
After the second sandwich has been allowed to stand for 10 minutes, it is ready for development. This standing time may be increased up to a maximum of about 35 minutes but the longer the sandwich stands and the more it dries down, the darker will the relief image tend to be. An excessive drying down period may produce dark marks on the pigment reliefs and will make it difficult to strip off the backing paper at the start of development.

DEVELOPMENT OF THE COLOUR RELIEFS

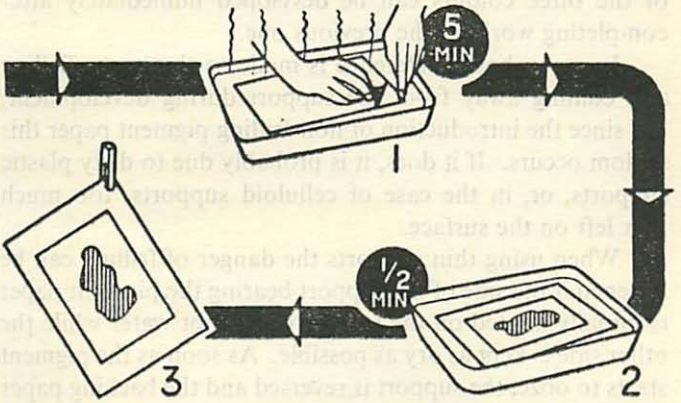
A dish or receptacle at least 3 in. longer each way than the support is filled with hot water at about 105° F. (40° C.).

The transparent support bearing the cyan pigment paper is then pushed below the surface of the water with the pigment uppermost.

After a few seconds the pigment will start to ooze from the edges and the backing paper may be stripped off (p. 61, No. 1), while the whole is kept well immersed below



The second sandwich. 1 Strip the first sandwich apart. 2 Bring transparent support and tissue in contact under water. 3 Squeegee together. 4 Leave to dry for 10 min. under slight pressure.



Developing the relief. 1 Immerse the second sandwich in hot water and separate. Move the relief about in the hot water for altogether some 5 min. 2 Place in a dish of cold water for ½-min. 3 Hang up to dry.

the surface of the water. It is unwise to wait too long before doing this, as air bubbles form on the pigment surface and if allowed to remain, they will cause markings on the developed relief. At this stage there is a mass of striated coloured pigment with a very faint suggestion of an image in the darker parts of the subject.

The support is moved about fairly rapidly under the surface of the water and occasionally lifted out and drained until the whole image is clear and no further colour runs from the print. The image may with advantage be given another brief rinse in clean warm water followed by about ½ minute in a dish of cold water to set the gelatine.

The support is then removed from the water, the surplus moisture blotted off the back, and put to dry. Drying may be hastened with a fan, but on no account must direct heat be used, as this may cause the thicker parts of the gelatine relief to leave the support.

The average time for development is about 5 minutes. If the tissues have been sensitised at 5-minute intervals, each of the three colours can be developed immediately after completing work on the previous one.

In many books reference is made to the image frilling and coming away from the support during development, but since the introduction of non-frilling pigment paper this seldom occurs. If it does, it is probably due to dirty plastic supports, or, in the case of celluloid supports, too much wax left on the surface.

When using thin supports the danger of frilling can be lessened if the side of the support bearing the pigment paper is initially floated on the surface of the hot water while the other side is kept as dry as possible. As soon as the pigment starts to ooze, the support is reversed and the backing paper peeled off under water. The object of this is to melt the layer of gelatine on the backing paper before softening the pigment next to the support.

TRIAL REGISTRATION

As soon as the relief images are dry, a trial registration can be made to get a general idea of what the finished print will look like.

First examine the backs of the cyan and magenta reliefs to see that there is no moisture or grit adhering to them. Lay the yellow relief face upward on a sheet of white paper. Place the magenta and cyan reliefs carefully on top and when registered hold the edges of the supports together with clips.

The effect produced will appear rather flat and lacking in density and even with experience it is extremely difficult to judge whether the colour balance and density of the final print will be satisfactory. For this reason it is strongly recommended that the print should be finished even if the colour balance appears to be quite wrong, as the chances of correctly estimating the adjustments required are small at this stage.

REDEVELOPMENT OF THE BROMIDES

After the bromides have been separated from the pigment papers at the completion of the first sandwich stage, they will be in a bleached condition.

Bleaching may not be complete in the darker parts of the prints, but it should be even.

Any dark spots will indicate that air was trapped in the sandwich and that the chemical action was not complete.

Very occasionally trouble is experienced with the bromides refusing to bleach. This is usually in districts where the tap water is very hard and contains excessive lime. The cure is to keep the washing times of the prints to a minimum and to use the acid rinse and buffer solution (pp. 36 and 52).

If the bleaching is patchy, it may be due to the prints

having been fixed in a hardening fixer, as this hardens the gelatine and tends to inhibit the bleaching action.

The bleached prints should be washed as thoroughly and quickly as possible, and then redeveloped, preferably in a plain metol developer. The formula given on p. 29 is suitable. At least 5 minutes' development should be given to make certain that the image is completely blackened.

If it develops slowly, the bichromate may not have been completely washed out or the hypo was not properly eliminated from the prints after fixing in the first place.

After redevelopment the prints should be washed for about a quarter of an hour.

Excessive washing or soaking should always be avoided as apart from the tendency for the prints to collect lime, the backing paper may mottle and this is liable to produce a similar effect in the colour reliefs themselves.

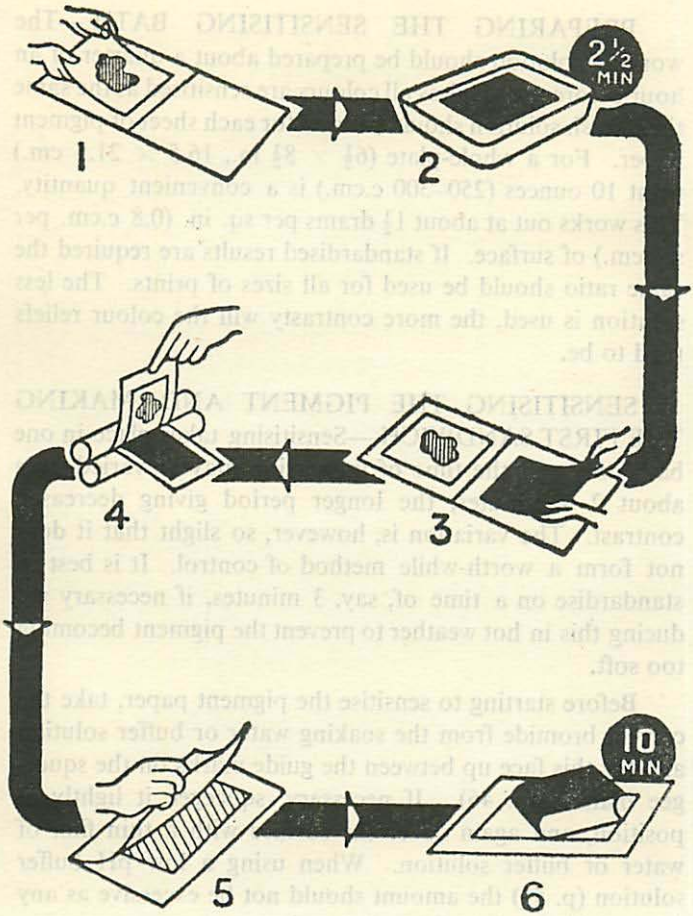
If the bromides are to be re-used the acid rinse should again be employed.

The same set of bromide prints may with care be re-used two or three times. However there is always a slight increase in density and contrast and two prints should be regarded as the maximum for best quality work.

The beginner is strongly advised to redevelop all his bromides and to record on the back the exposure, developer, time of immersion in the No. 2 sensitiser bath and other relevant details. This will be useful if another print is to be made at a later date, and will also form a guide as to the printing density and contrast required when dealing with a similar type of subject.

SINGLE BATH PROCESS

As the working procedure for the two-bath method has already been described, only those points in which the technique differs are dealt with below.



Sensitising and first sandwich in the single-bath process. 1 Place soaked bromide print from red filter negative face up on squeegee blanket. 2 Immerse cyan tissue in the sensitiser for about 2½ min. (can be varied, p. 66). 3 Drain, and place tissue face up on other half of squeegee blanket. 4 Feed the blanket through the wringer to squeegee print and tissue together. 5 Blot. 6 Place between waxed paper under slight pressure for about 10 min. Repeat all operations with the magenta and yellow tissues.

PREPARING THE SENSITISING BATH.—The working solution should be prepared about a quarter of an hour before use. Unless all colours are sensitised at the same time, fresh solution should be used for each sheet of pigment paper. For a whole-plate ($6\frac{1}{2} \times 8\frac{1}{2}$ in., 16.5 × 21.5 cm.) print 10 ounces (250–300 c.cm.) is a convenient quantity. This works out at about $1\frac{1}{2}$ drams per sq. in. (0.8 c.cm. per sq. cm.) of surface. If standardised results are required the same ratio should be used for all sizes of prints. The less solution is used, the more contrasty will the colour reliefs tend to be.

SENSITISING THE PIGMENT AND MAKING THE FIRST SANDWICH.—Sensitising takes place in one bath only and the time of immersion may be varied from about 2–4 minutes, the longer period giving decreased contrast. The variation is, however, so slight that it does not form a worth-while method of control. It is best to standardise on a time of, say, 3 minutes, if necessary reducing this in hot weather to prevent the pigment becoming too soft.

Before starting to sensitise the pigment paper, take the correct bromide from the soaking water or buffer solution and lay this face up between the guide marks on the squeegee blanket (p. 46). If necessary, squeegee it lightly in position, and again cover the surface with a thin film of water or buffer solution. When using a low pH buffer solution (p. 53) the amount should not be excessive as any drops falling on the face of the pigment paper may cause areas of uneven density.

Immerse the pigment paper in the sensitiser. After the scheduled time has elapsed, remove it from the solution, hold it vertically for a few seconds to drain, and lay it face up in position on the other half of the squeegee blanket. If it is carefully placed it should be unnecessary to squeegee

it, but there is no harm in doing this gently, as it will also remove the surplus sensitiser.

Insert the ends of the squeegee blanket into the wringer holding the two halves well apart (see p. 65, No. 4). As soon as the rollers have got a grip, the handle of the wringer can be turned fairly quickly. The complete blanket is passed through the rollers in this way, the upper blanket being held at an angle to the lower throughout the process.

When working with the wringer in the usual horizontal position, the bromide should be on the upper of the two blankets as this will avoid the possibility of any drops of sensitising solution falling on it.

The sandwich may be removed and put between waxed paper or left in the blanket. In the latter case contact between the sandwich and blanket must be maintained. Alternatively, remove the sandwich completely, blot it carefully, dry the blanket and then put it back. The important point is to ensure that any drying down which occurs takes place evenly over the whole surface of the sandwich.

TRANSFER TO SOLUBLE TEMPORARY SUPPORT

This is the second stage of the process. The cyan, magenta, and yellow images are each in turn transferred to a soluble temporary support.

This is a strong thin paper, coated with a layer of gelatine which is soluble in hot water. It will be referred to throughout this chapter by the abbreviated title of S.T.S. = Soluble Temporary Support.

Although it is possible to transfer the images direct to a final support (see p. 77), the method is not recommended as a standard working procedure.

PREPARING THE SOLUBLE TEMPORARY SUPPORT

In order to obtain trouble-free registration of the colour images, the S.T.S. must be very fully stretched. The most certain way of doing this is to soak it for at least half an hour in water at 60–70° F. (15–21° C.) then squeegee it on to a transparent plastic support and dry it down until it strips off. Immediately before use it is resoaked for 2-3 minutes in water between 70° and 80° F. (21–27° C.) when the surface will become slimy, indicating that the gelatine is soft and will easily pick up the colour relief.

If a waxed celluloid support was used for the drying down process, the wax must be removed from the surface of the S.T.S. before resoaking it (p. 72).

It is not necessary to dry down the S.T.S. on a support ; as initial soaking followed by a good squeegeeing will take most of the stretch out of the paper, but this is unlikely to be entirely satisfactory for the larger sizes of prints.

Provided the S.T.S. is put to soak in the early stages of making the colour print, the first method does not take much longer and it is probably wise to adopt it as standard procedure.

TRANSFER OF CYAN RELIEF

The cyan image with its transparent support is put into the same dish of water as the S.T.S. and the two brought together under water with the plain side of the plastic support uppermost. Any air bells or foreign matter which has been trapped in the sandwich can be seen through the plastic and eliminated.

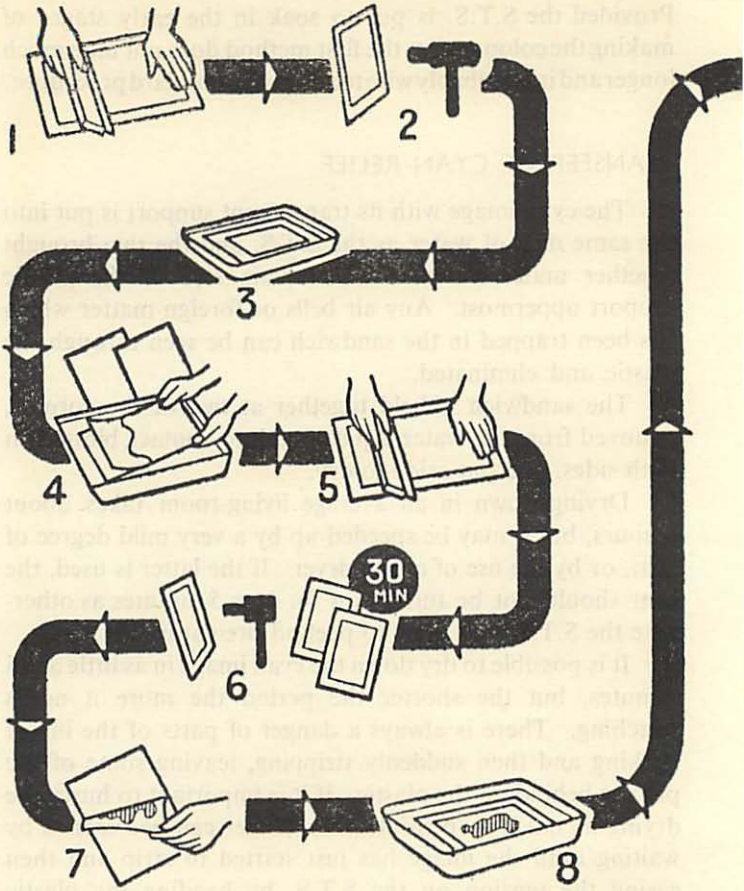
The sandwich is held together at two of the corners, removed from the water, squeegeed into contact, blotted on both sides, and put aside to dry.

Drying down in an average living-room takes about 4 hours, but it may be speeded up by a very mild degree of heat, or by the use of a hair dryer. If the latter is used, the heat should not be turned on for 4 or 5 minutes as otherwise the S.T.S. may start to peel off prematurely.

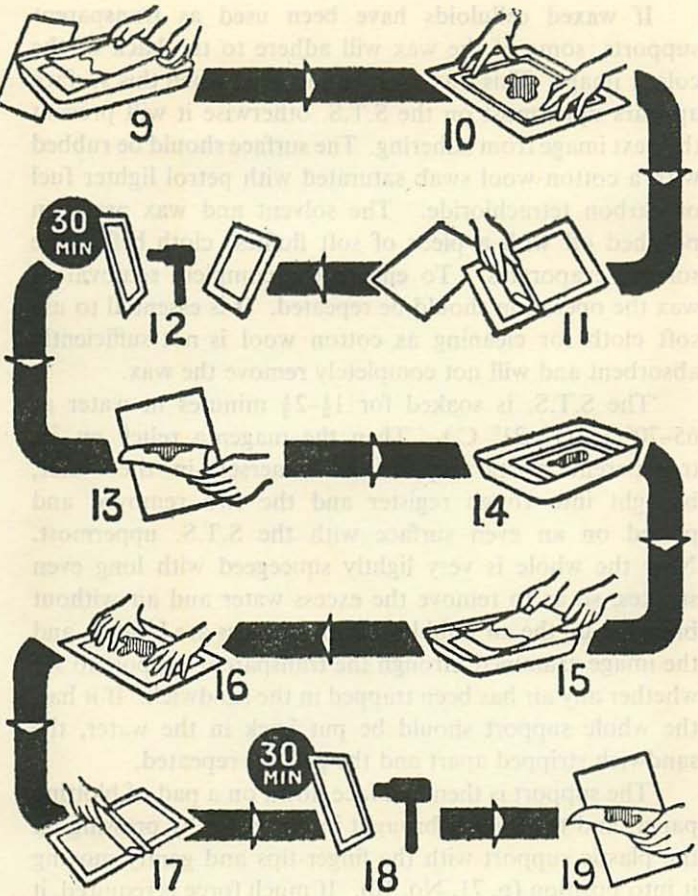
It is possible to dry down the cyan image in as little as 15 minutes, but the shorter the period the more it needs watching. There is always a danger of parts of the image sticking and then suddenly stripping, leaving some of the picture behind on the plastic. If it is important to hurry the drying as much as possible, this danger can be lessened by waiting until the image has just started to strip and then easing the tension on the S.T.S. by bending the plastic support slightly inwards and keeping it in this position until drying is complete.

TRANSFERRING THE MAGENTA RELIEF

The S.T.S. now has the cyan image on it, and the next step is to superimpose the magenta relief.



Transfer to soluble temporary support. 1 Squeegee the soaked S.T.S. on to a transparent support to stretch it. 2 Dry until the S.T.S. strips off. 3 Resoak the S.T.S. for 2–3 min. 4 Bring into contact under water with the transparent support carrying the cyan relief. 5 Squeegee together. 6 Dry down for about 30 min. with forced heat (e.g., from a hair dryer), or for about 4–5 hours normally. 7 Strip off the transparent support, leaving the cyan relief on the S.T.S. 8 Resoak the S.T.S. with the relief on it.



9 Bring into contact under water with transparent support carrying magenta relief. 10 Register the cyan and magenta images accurately. 11 Squeegee together. 12 Dry down. 13 Strip off transparent support leaving magenta relief on top of cyan relief on the S.T.S. 14 Resoak S.T.S with two reliefs. 15 Bring into contact under water with transparent support carrying yellow relief. 16 Register the yellow image accurately with the other two. 17 Squeegee together. 18 Dry down. 19 Strip off transparent support, leaving yellow relief on top of the other two on the S.T.S.

If waxed celluloids have been used as transparent supports, some of the wax will adhere to the back of the colour image. This wax must be removed when this surface appears uppermost on the S.T.S. otherwise it will prevent the next image from adhering. The surface should be rubbed with a cotton wool swab saturated with petrol lighter fuel or carbon tetrachloride. The solvent and wax are then polished off with a piece of soft fluffless cloth before the solvent evaporates. To ensure the complete removal of wax the operation should be repeated. It is essential to use soft cloth for cleaning as cotton wool is not sufficiently absorbent and will not completely remove the wax.

The S.T.S. is soaked for 1½–2½ minutes in water at 65–70° F. (18–21° C.). Then the magenta relief on its transparent plastic support is immersed in the water, brought into rough register and the two removed and placed on an even surface with the S.T.S. uppermost. Now the whole is very lightly squeegeed with long even strokes, so as to remove the excess water and air without breaking up the air bubbles. Both surfaces are blotted, and the image examined through the transparent support to see whether any air has been trapped in the sandwich. If it has, the whole support should be put back in the water, the sandwich stripped apart and the process repeated.

The support is then laid face down on a pad of blotting paper, and the images brought into register by pressing on the plastic support with the finger-tips and gently moving it into position (p. 71, No. 10). If much force is required, it will mean that either the squeegeeing pressure was too great or that the cyan image was not soaked long enough before making the sandwich. The remedy is to put the sandwich back into the water, strip it apart and start again. It is well worth while using a watchmaker's eyeglass to assist in the last stages of registering.

Sometimes one of the images is larger or smaller than

the other and refuses to register. There are a number of possible causes for this which will be found listed in the defects table on p. 90. The most likely reason, however, is that the S.T.S. has not been properly stretched.

The best way of dealing with the situation is accurately to register one end or side of the print and to squeegee it firmly into position. Then the plastic support is bent inwards or outwards until the other end of the print registers.

The support is fixed in this position with wire. Some workers drill holes in all four corners of the support and thread wires through them so that the support can be bent in any direction. This method is certainly effective, but it is better to try and find the cause of the images not registering and to eliminate that. Small adjustments can be made by holding one part of the print and gently pulling or pushing the other part into register ; it may be necessary to hold this in position until the image dries sufficiently to adhere.

TRANSFERRING THE YELLOW RELIEF

After drying down, the yellow image is transferred on to the S.T.S. in a similar manner.

It is important that the temperatures and times laid down should be adhered to fairly closely. If the soaking water for the S.T.S. is too cold, it will not pick up the relief image, and if it is too hot, the gelatine becomes soft and easily damaged.

Prolonged soaking of the relief image, either when on the plastic support, or on the S.T.S., will increase the difference in height (relief) between the lighter and darker parts of the image and make it more difficult for the transfer to take place.

TRANSFER TO FINAL SUPPORT

This is the third stage of working the trichrome carbro process.

We now have the S.T.S. with the three colour images on it, the picture is reversed from right to left and has a distinctly yellow tinge due to the rather opaque yellow image being uppermost.

The last operation consists of transferring the whole print to its final support.

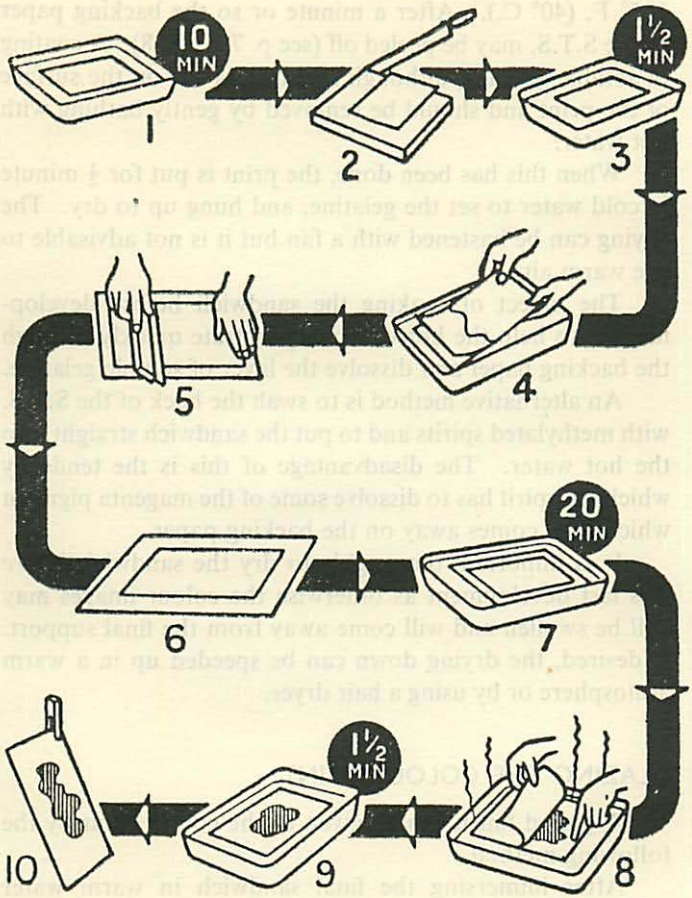
TRIMMING THE PRINT

If a cut mask is not going to be used on the final print, the unwanted parts of the picture should be trimmed away. This will of course include the grey scale. If the worker is really conscientious, he will not throw this away, but will make a separate final transfer of it, as it is difficult to judge colour balance with the yellow pigment uppermost.

THE FINAL SANDWICH

A sheet of single transfer paper which is coated with hardened gelatine is put to soak for about 10 minutes in water at 60–70° F. (15–21° C.). At the end of this period, the S.T.S. with its adherent images is soaked for ¾–1½ minutes, and then squeegeed into contact with the final support. Surplus moisture is blotted off and the whole allowed to dry thoroughly.

The sandwich is put to soak for 20 minutes in water at 60–70° F. and then transferred into warm water about



Transfer to final support. 1 Soak final support for about 10 min. 2 Trim the assembled print on the S.T.S. 3 Soak S.T.S. with the relief on it. 4 Bring the S.T.S. with the assembled reliefs into contact under water with the final support. 5 Squeegee together. 6 Leave until dry (do not use heat). 7 Soak in cold water for 20 min. 8 Immerse in hot water and strip off S.T.S., leaving the relief images on the final support. 9 Immerse in cold water for ½ min. 10 Hang finished carbro print up to dry.

105° F. (40° C.). After a minute or so the backing paper of the S.T.S. may be peeled off (see p. 75, No. 8). A coating of soluble gelatine, although invisible, is left on the surface of the print and should be removed by gently bathing with hot water.

When this has been done, the print is put for ½ minute in cold water to set the gelatine, and hung up to dry. The drying can be hastened with a fan but it is not advisable to use warm air.

The object of soaking the sandwich before development is to help the hot water to penetrate quickly through the backing paper and dissolve the layer of soluble gelatine.

An alternative method is to swab the back of the S.T.S. with methylated spirits and to put the sandwich straight into the hot water. The disadvantage of this is the tendency which the spirit has to dissolve some of the magenta pigment which then comes away on the backing paper.

It is important thoroughly to dry the sandwich *before* this last development as otherwise the colour images may still be swollen and will come away from the final support. If desired, the drying down can be speeded up in a warm atmosphere or by using a hair dryer.

GLAZING THE COLOUR PRINT

A glazed finish can be given to the colour print by the following method.

After immersing the final sandwich in warm water and stripping off the support backing paper (p. 76) the clear soluble gelatine is *not* washed away. Instead, the print is dipped into a 10 per cent solution of gelatine containing a trace of formalin. It is then squeegeed on to a really clean and scratch-free glazing surface such as plate glass, chromium plated metal sheet or new Perspex, and allowed to dry naturally, without the use of heat.

In order to prevent the gelatine setting immediately it touches the glazing surface and causing bubbles or other markings, it is advisable to warm the surface slightly. After squeegeeing, chill in cold water and allow drying to proceed naturally.

Plate glass may be cleaned by using a proprietary window and glass cleaning solution which often consists of a suspension of French Chalk or Tripoli powder in spirit.

SINGLE OR DIRECT TRANSFER

Double transfer can be regarded as the normal method for making colour prints. The procedure has been fully described and involves the use of a soluble temporary support. The advantages over single transfer in which the colour reliefs are transferred direct to the final support are :

(*a*) Combination of the colour reliefs takes place in the order cyan, magenta, yellow, which is visually easy for registration. In single transfer the images are combined in the reverse order and it is difficult to detect faulty register when superimposing the magenta on the yellow. It is emphasised that in the final print the cyan must always be on top with the magenta and yellow beneath in that order.

(*b*) Double transfer protects the all-important cyan image until final transfer is completed.

(*c*) The soluble temporary support is particularly suited for picking up all details from the colour relief and the final transfer can be made on to a rough paper surface. For single transfer a smooth surface is imperative.

(*d*) The use of a thin paper such as the soluble temporary support speeds up drying operations.

The chief advantage of single transfer is a slight saving in time and this may be useful for experimental work. The only differences in working procedure from double transfer are :

(*a*) Unless the picture is to be reversed from right to left, the separation negatives must be turned round in the enlarger.
(*b*) The colour reliefs are transferred direct from their transparent supports to the final support.
(*c*) The sequence of registration must be yellow, magenta and cyan, so that the colour reliefs in the print are in their correct order with the cyan on top.

TRANSPARENCIES

By varying the transfer procedure, the process can be used for making transparencies on glass or other support.

The colour reliefs will need to be rather heavier and more contrasty than normal, and the colour balance should be matched under conditions of illumination similar to those under which the transparency will be used. For projection purposes it is advisable to work with Series 3 pigment (p. 39) and to obtain the special transparent yellow which is made for this purpose.

One of the following methods of working is recommended :

(*a*) Using the normal working procedure but making the final transfer to glass or some other transparent support.
(*b*) Instead of squeegeeing the pigment paper on to the normal transparent support, very thin sheets of unwaxed celluloid are used. After development and drying these are bound up in register.

Almost any support can be used for the final transfer provided that it is first covered with a hardened coat or coats of gelatine and will withstand the warm water used for removing the temporary support backing paper.

To apply the hardened gelatine layer a 2 per cent solution of hard gelatine is made up, e.g., Nelson's No. 1. Sufficient potassium bichromate is added just to colour the solution a pale orange yellow (about 0.15 per cent). The gelatine solution is strained through fine muslin and poured on to the support which must be clean and free from grease. The surplus gelatine is drained off and the coating allowed

to dry. In order to harden the gelatine the drying must take place in a strong actinic light.

An alternative method of hardening the gelatine is to use chrome alum. This has the advantage that it does not discolour the gelatine as much as bichromate. The amount of chrome alum which should be added to the gelatine depends on its characteristics, but the following procedure is usually satisfactory.

A 5 per cent solution of gelatine is made up, tested with litmus paper, and, if acid, neutralised with ammonia. Then 1 part of 5 per cent chrome alum solution is added for every 32 parts of gelatine solution. After coating with this mixture the support should be placed in a horizontal position until the gelatine has started to set. The coating so obtained is thicker than that given by the bichromate method. If the support is porous, more than one coating may be given.

Instead of coating glass with gelatine spoilt plates can be bleached, fixed, hardened, and washed. For hardening, the plates should be given 15 minutes' immersion in a 5 per cent solution of chrome alum. The use of formalin is not recommended, for if the plates are not washed very thoroughly and allowed to stand for several days, the formalin will harden the soluble temporary support and prevent the backing paper peeling off during final transfer.

THE FINISHED PRINT

When the print is finished, it should be examined by daylight or daylight corrected artificial light, to see whether it can be improved. If it is the first print made from the negatives in question, this will almost certainly be the case.

Apart from the mechanical faults such as faulty registration, spots, etc., defects in the rendering of the subject can be due to colour balance, colour saturation or density.

COLOUR BALANCE

Faulty colour balance if at all pronounced is obvious from looking at the print and comparing it with the original.

The grey scale will also provide a useful guide. Although due to the imperfections of the colour dyes a perfect grey does not always produce the most satisfactory rendering in the print, the margin of permissible variation is small. If the steps of the grey scale vary in colour, it indicates that the pigment images were not of equal contrast. This may be due either to the bromides not having been correctly balanced (see p. 29), or if the two-bath sensitising method was used, the pigment papers may have been given different times of immersion in the No. 2 bath. Another possible cause is the mixing of different sets of tricolour pigment, as the characteristics of the pigment papers vary slightly between batches (see p. 125).

Although it is comparatively easy to detect any differences in contrast by looking at the grey scale it needs some experience to do so from the print itself. It is quite easy to waste a lot of time in varying the exposures of the

bromides and making new prints before finding out the real cause of the trouble. This is one very good reason why a grey scale should always be included in the subject and not cut out of the picture until the final transfer stage.

Assuming that the print and grey scale show that the bromides were out of balance, the next problem is to decide what relative adjustment to the exposures of the bromides is required and whether to one or two of the colours.

This is again largely a matter of experience, but it is a great assistance to view the print through fairly large gelatine filters dyed in the three printing colours. Ideally a number of these are required with gradually increasing colour density. A complete set of filters is, however, rather an expensive item and two or three of each colour are sufficient to serve as a useful guide.

The worker can make quite satisfactory substitutes by dyeing up sheets of gelatine. Commercial transparent red, yellow and blue photo tints are quite suitable and may also be used for retouching the colour print. For best results the filters should be a minimum of 2 in. square and the lightest should have a barely perceptible colour tinge.

By viewing the print through a combination of filters it is fairly easy to decide which of the three colours need alteration. The following is an indication of the sort of alterations which may be required.

COLOUR BALANCE ADJUSTMENTS

Appearance of Print	*Adjustment*
Print satisfactory, but could be improved by very slight change of colour balance	Reduce exposure of bromide print responsible for the excess colour by 4 per cent
Print passable, but noticeably out of balance	Reduce exposure of bromide print responsible for the excess colour by 7 per cent
Pronounced lack of balance	Reduce exposure of bromide print responsible for excess colour by 12 per cent or more

If the print is already thin, the exposures for the bromide prints responsible for the reliefs in which colour is lacking can be increased in the same way.

The effect of any given percentage alteration will be governed by the contrast of the bromide paper and developer used. If it is decided that only a small increase (say 6 per cent) is required in one of the colours, it is sometimes worth while to re-use the same bromides and to obtain the increased density by giving extra drying down time to the appropriate tissue whilst in the second sandwich stage (p. 60).

Various methods have been suggested for reducing any of the pigment images either at the transparent support stage, or when combined in the final print. The chief disadvantage of the former is that it is difficult to judge the amount of reduction necessary before the print is assembled whilst in the latter case no reducer is sufficiently selective in its action to be recommended.

The amateur who wishes to improve his technique should avoid tinkering with the print in this way, but occasions do arise where it may be worth while trying to save a print which would otherwise have to be thrown away. Possible methods may be divided into two classes, chemical and mechanical.

CHEMICAL REDUCTION OF COLOUR IMAGES. —*Photo-Bias* is a complex chemical substance which has the property of softening gelatine. It should only be used on the relief images at the transparent support stage and if these are dry they should be soaked for 3–5 minutes in cold water.

To use this method : make up a 2 per cent solution of Photo-Bias and immerse the colour relief in it for a few seconds until the colour begins to run. Then develop the softened gelatine away in warm water. If further reduction

is required, the treatment can be repeated several times. This method ensures that the reduction does not get out of hand and is better than giving a longer initial immersion.

The solution of Photo-Bias can be re-used several times and may be kept for a month or so, until the smell becomes too pronounced.

A 5–15 per cent solution of plain hypo is usually effective in reducing the yellow pigment. The relief on its support is immersed in the solution and reduction should take between 15 seconds and 1½ minutes, depending on the decrease of density required and the strength of the solution. It is important to watch the highlights carefully to see that all the pigment is not removed. After treatment the relief should be given a thorough wash by passing it through a number of changes of water.

MECHANICAL REDUCTION OF COLOUR IMAGES.—Mechanical reduction consists of rubbing the reliefs with methylated spirits or some form of fine powder abrasive. It is best carried out after the relief has been transferred to the soluble temporary support. In the case of the cyan relief, it can also be done after the print has been assembled. This latter method is not so satisfactory, as the final support does not give as smooth a base to work on as the S.T.S.

The methylated spirits dissolves the pigment and there is a danger of producing high-water marks or carrying the pigment into other parts of the print. The best way is to remove only a little at a time and to allow the spirit to evaporate after each application. With care it is possible to reduce the whole area of relief to quite a large extent.

COLOUR SATURATION

The effect of varying the contrast in a colour print is not only to increase tonal contrast, but also to alter the

saturation of the colours (p. 130). In practice this means that in the case of increased contrast the colours are accentuated and appear vivid, while with lowered contrast they look muddy.

From a theoretical point of view the contrast of the print is determined at the moment of taking the subject and will only be correct when the density range of the grey scale in the print approximates to that of the original. In practice there is a certain amount of latitude in producing an acceptable result, but if the lighting contrast range of the subject was too great for the process, it is impossible to produce a satisfactory print (see p. 133).

DENSITY

If the finished print is too light or too dark, the normal remedy is to remake the bromides and adjust the printing exposures. A slight overall increase in density can be obtained by re-using the same bromides and giving a longer drying down time in the first sandwich.

The density of the print is not as critical as colour balance, but where the subject is of high key or covers a relatively great brightness range, it will be found necessary to print the highlights as lightly as possible. The minimum density in the bromides which will just be retained by the pigment image varies with the type of paper used, the composition of the sensitiser and with the efficiency of the technique in squeegeeing the first sandwich. For best results with the single bath sensitiser, extra acid should be added to the bath and the drying down time in the second sandwich kept to the minimum.

In judging the minimum density required on the bromide, it will be found helpful to mask out a portion of the highlight in one of the bromide test strips, to provide a direct comparison with the unexposed white of the paper.

Bromides which have been redeveloped always show a slight increase in contrast and density, consequently when the subject is one in which the minimum highlight density is particularly important, a fresh set of bromides will have to be made for each print.

SPOTTING AND MOUNTING

However carefully the print has been made, some spotting is likely to be required. This can be done by using the tricolour dyes which are supplied in solid form. These may also be used in the form of a wash to touch up the colour of small areas in the print.

As is usual with work of this kind, best results are obtained by using several weak washes in preference to trying to obtain the required result with one application.

The finished print may be dry-mounted, but the iron temperature is rather critical. If it is too hot, the gelatine may melt and stick to the mounting plate. This difficulty can be overcome by hardening the print for 5 minutes in a 5 per cent solution of formalin, or by giving slightly longer in a 5 per cent alum bath followed by a good rinse.

On the whole, rubber solution mounting is probably the easier method.

If a more glossy finish is required, the surface of the print can be treated with a wax polish. The trichrome celluloid waxing compound is suitable and even wax floor polish can be used with success.

FAULTS AND THEIR CAUSES

FAULTS IN THE FINISHED PRINT

Fault	*Cause*	*See page*
Too light	(*a*) Bromide prints too light. Remake bromides or if the desired increase in density is small, extend drying down period in second sandwich	82
	(*b*) Insufficient washing after giving bromides acid rinse	36
Too dark	(*a*) Bromide prints too dark	84
	(*b*) Excessive drying down in second sandwich	60
Too flat	(*a*) Bromide prints too flat. Remake, or for :	
	two-bath sensitiser decrease time of immersion in second bath	56
	single bath sensitiser decrease acid content	45
	(*b*) Insufficient washing of bromides after acid rinse	36
Too contrasty	(*a*) Bromide prints too contrasty ; remake or for :	32
	two-bath sensitiser increase time of immersion in second bath	56
	single bath sensitiser increase acid content	45
	(*b*) Temperature of sensitising solutions abnormally high	55
	(*c*) Potassium bichromate has crystallised out of sensitiser stock solution, and has not been re-dissolved before use. Warm solution and shake until crystals dissolve	46

Fault	*Cause*	*See page*
Highlight detail not retained	(*a*) Highlight tone in bromides too light. Remake or try increasing drying down time in second sandwich	84
	(*b*) Too short an immersion in No. 2 sensitising bath or too little acid in the single bath sensitiser	45
	(*c*) Delay after the initial contact between the bromide and sensitised pigment paper and completion of the squeegee operation	59
	(*d*) Tap water contains excessive lime. Keep washing times to a minimum, give bromides acid rinse, and soak in a buffer solution prior to use.	52
	(*e*) Tap water is alkaline. Use buffer solution	52
All-over tinge	(*a*) Bromide prints not in balance or not adjusted to suit the batches of pigment papers in use	80
	(*b*) Check on working technique to ensure that all three colours receive similar treatment throughout the process	49
Colour correct in some parts of subject but not in others	(*a*) Mixed types of lighting used when photographing the subject. Re-take the subject or use local control when making the bromides	36
	(*b*) A focal plane shutter was used for exposing the negatives and the speed of travel of the blind was erratic	21
	(*c*) Uneven processing of the separation negatives	24
	(*d*) Negatives and/or bromides incorrectly marked with their respective printing or filter colour	21
	(*e*) The enlarger illumination was uneven and each of the negatives did not occupy the same position in the enlarger	33
	(*f*) Bromide prints not balanced for contrast. Examine grey scale for uniformity	80
	(*g*) Uneven treatment of pigment paper during sensitising or subsequent operations	

Fault	*Cause*	*See page*
Lack of standardisation in colour rendering between different prints made from the same negatives	Working procedures not standardised	117
Whites stained with colour	(*a*) Development of colour reliefs incomplete	62
	(*b*) Bromide prints not in balance or fogged	80
	(*c*) Surface of bromide prints dirty	
	(*d*) Dirty working conditions	
	(e) The pigment paper was exposed to strong daylight during sensitising or subsequent operations	
	(*f*) Impure chemicals	45
Mottle	In general mottle is caused by variations in the closeness of contact between the bromide and pigment paper in the first sandwich. Specific causes are :	
	(*a*) Very light squeegee pressure	
	(*b*) Overwashing or soaking of bromides. If the paper base becomes mottled it is wiser not to use the prints.	36
	(*c*) Excessive immersion time of pigment paper in the sensitiser, particularly if working at a high temperature.	66

Fault	*Cause*	*See page*
Bromides bleach unevenly	(*a*) Use of unsuitable bromide paper. Always use unsupercoated paper	27
	(*b*) Use of a hardening fixer, when making the bromide prints. Any hardening of the gelatine inhibits chemical action in the first sandwich	35
Bromides will not bleach	(*a*) Bleaching is not always complete in the shadow areas but if the middle tones are also affected, it is probably due to excessive lime in the water. Keep washing time of bromides to a minimum, use acid rinse and buffer solution	36, 52, 63
	(*b*) Soft water containing large quantities of iron. Remedy as for (*a*) above	
Black spots on bleached bromides	Air has been trapped between pigment paper and bromide in first sandwich. (Do not use wetting agent as it tends to cause excessive swelling of gelatine)	63
Pigment paper will not strip from bromide	(*a*) First sandwich has dried down too much	60
	(*b*) The pigment has melted. In hot weather avoid touching sandwich with hands.	55
	(*c*) Workroom temperature too high	55
	(*d*) Squeegee pressure excessive	
	(*e*) Temperature of sensitising solutions too low	55
Bromides will not redevelop or develop slowly	(*a*) Insufficient washing before redevelopment	64
	(*b*) Hypo has not been completely eliminated from the bromides	
Relief image will not develop	(*a*) Pigment paper old or badly stored. Test whether a piece of unsensitised pigment will dissolve in hot water	40
	(*b*) Too much formalin in the sensitiser	

Fault	*Cause*	*See page*
Pigment frills and comes away from support during development	(*a*) Plastic supports dirty	41
	(*b*) If celluloid supports have been used, they were insufficiently polished after waxing	41
	(*c*) Insufficient squeegee pressure at second sandwich stage	
	(*d*) Working temperatures too high or excessive immersion time during sensitising	55
	(*e*) Use of heated softened water for development. Add proportion of hard cold water	
Relief comes away from support during drying	Heat was used to speed the drying. Drying can be accelerated by a fan, but warm air must not be used	62
Colour relief will not strip from plastic	(*a*) Plastic supports which do not require waxing sometimes fail until they have had an initial cleaning with metal polish	41
	(*b*) Plastic supports dirty. A trace of metal polish will prevent the image stripping	41
	(*c*) Plastic supports have become matt and porous. Use one side only and preserve it from scratches	41
	(*d*) If celluloid supports have been used, the wax may have been unsuitable, not properly applied, or alternatively it was not removed from the surface of the colour image before combining it with the next relief.	72
	(*e*) Soaking soluble temporary support in water which was too cold	68
	(*f*) Inclusion of air between plastic and soluble temporary support	69
	(*g*) Faulty drying down technique	69
	(*h*) Local reduction of colour images after transfer to S.T.S. roughens the surface and makes it harder for the next image to adhere.	
Colour images will not register	(*a*) Camera or subject moved between taking the three separation negatives	
	(*b*) Negatives were not in the same plane when photographing the subject. Check plate holders or in the case of a roll film camera, ensure that film pressure plate is holding the film flat	

Fault	*Cause*	*See page*
	(*c*) The camera lens was not sufficiently corrected for chromatic aberration and did not bring the three filter images to the same point of focus	
	(*d*) Slight movement of the enlarger or cockling of the bromide paper when making the prints	33
	(*e*) Bromide paper or pigment paper not all cut from the same direction of the parent roll or sheet	28
	(*f*) Bromide prints have not been soaked for the same time, or have not been given sufficient time to expand	52
	(*g*) Similar squeegee treatment was not given to each bromide or pigment paper in making first or second sandwich	
	(*h*) Soluble temporary support not soaked or stretched sufficiently before commencing transfer	68
	(*i*) S.T.S. overexpanded. If it was stretched by drying down on a support, it should not be soaked for more than 2–3 minutes before bringing it into contact with the cyan image.	68
Surface blemishes appear on colour reliefs during registration	(*a*) Grit trapped between colour reliefs	
	(*b*) Insufficient soaking before attempting to register or soaking in water which is too warm	72
	(*c*) Moving reliefs after they have begun to adhere firmly to each other	72
	(*d*) Carrying out the operation at too high a temperature. (75° F. is about the limit.)	
Backing paper of temporary support will not strip off	Gelatine of temporary soluble support has become insoluble due to bad storage	
Image comes away from final support during development	(*a*) Final sandwich (temporary and final support) not dried down long enough before development	76
	(*b*) If celluloid supports were used the wax may not have been removed from the yellow image before making the final sandwich	72

AVERAGE WORKING CHARTS

These charts are intended as a guide during the actual making of the print. They tell at a glance what step follows, and how the time schedule should run. The times given are for average speed in operation, enabling each step to be completed in comfort without rush.

The charts are divided into stages ; each stage can be carried through at a different time—on different days, if necessary.

The steps marked* apply to the two-bath sensitiser only. The corresponding steps for the single bath sensitiser will be found on p. 98–99.

STAGE I : PREPARING THE RELIEFS

Step	*Time on Clock (Mins.)*	*Operation*	*Time Taken (Mins.)*	*See page*
1.	—	*GETTING READY*	30	
		(*a*) Put soluble temporary support to soak in cold water at 60–70° F. (15–21° C.)		68
		(*b*) Lay out work bench		51
		(*c*) Clean and polish transparent supports (or wax the celluloids)		40
		(*d*) Put bromides to soak		52
		(*e*) Get squeegeeing apparatus ready		46
		(*f*) Mix sensitiser solutions and pour into dishes		55
		(*g*) Have pigment paper ready		39
		SENSITISING AND FIRST SANDWICH		
* 2.	0	Set clock	—	
* 3.	0	Immerse cyan tissue for 2 minutes in No. 1 sensitiser bath	2	56

STAGE I (contd.)

Step	Time on Clock (Mins.)	Operation	Time Taken (Mins.)	See page
* 4.	2	Remove the tissue from sensitiser and squeegee face down on a clean sheet of glass	½	56
* 5.	2½	Take print from red filter negative out of soaking water and squeegee face up on a sheet of glass. Pour a little water over surface	1	
* 6.	3½	Immerse tissue in No. 2 bath (normally for 20 seconds)	½	58
* 7.	4	Squeegee tissue on to bromide print	½	58
* 8.	4½	Remove sandwich from glass, blot both sides, and put between wax paper for not less than 10 minutes	½	59
* 9.	5	Immerse magenta tissue for 2 minutes in No. 1 bath	2	56
*10.	7	Remove tissue from sensitiser and squeegee face down on a clean sheet of glass	½	56
*11.	7½	Take print from green filter negative out of soaking water and squeegee face up on a clean sheet of glass. Pour a little water over surface	1	
*12.	8½	Immerse magenta tissue in No. 2 bath (normally for 20 seconds)	½	58
*13.	9	Squeegee tissue on to bromide print	½	58
*14.	9½	Remove sandwich from glass, blot both sides, and put between wax paper for not less than 10 minutes	½	59
*15.	10	Immerse yellow tissue for 2 minutes in No. 1 bath	2	56
*16.	12	Remove tissue from sensitiser and squeegee face down on a clean sheet of glass	½	56
*17.	12½	Take print from blue filter negative out of soaking water and squeegee face up on a clean sheet of glass. Pour a little water over surface	1	
*18.	13½	Immerse yellow tissue in No. 2 bath (normally for 20 seconds)	½	58
*19.	14	Squeegee tissue on to bromide print	½	58

Step	Time on Clock (Mins.)	Operation	Time Taken (Mins.)	See page
*20.	14½	Remove sandwich from glass, blot both sides, and put between wax paper for not less than 10 minutes	½	59
*21.	15	Clear up work bench	3	
		SECOND SANDWICH		
22.	18	Take cyan sandwich and strip apart	1	59
23.	19	Immerse transparent support and tissue in water and bring the two into contact	½	59
24.	19½	Remove from water, and squeegee the two firmly together to form second sandwich. Blot and put between wax paper for at least 10 minutes	1½	59
25.	21	Put bleached bromide print to soak in a dish of cold water, preparatory to washing. Clear up work bench	2	60
26.	23	Take magenta sandwich and strip apart	1	59
27.	24	Immerse transparent support and tissue in water and bring the two into contact	½	59
28.	24½	Remove from water, and squeegee the two firmly together to form second sandwich. Blot and put between wax paper for at least 10 minutes	1½	59
29.	26	Put bleached bromide print to soak in a dish of cold water, preparatory to washing. Clear up work bench	2	60
30.	28	Take yellow sandwich and strip apart	1	59
31.	29	Immerse transparent support and tissue in water and bring the two into contact	½	59
32.	29½	Remove from water, and squeegee the two firmly together to form second sandwich. Blot and put between waxed paper for at least 10 minutes	1½	59
33.	31	Put bleached bromide print to soak in a dish of cold water preparatory to washing. Clear up work bench and get ready for developing	4	60

Step	Time on Clock (Mins.)	Operation	Time Taken (Mins.)	See page
		DEVELOPMENT		
34.	35	Immerse cyan image on its support in hot water at 105° F. (40° C.). As soon as pigment starts to ooze from the edges of the sandwich, peel off the pigment backing paper, keeping the support under the surface of the water	¼	60
35.	35¼	Move support about under water until all surplus pigment has been washed away from the colour relief	4¼	62
36.	39½	Immerse for about ½ minute in cold water to set the gelatine, blot back of transparent support, and put cyan relief to dry	½	62
37.	40	Immerse magenta image on its support in hot water at 105° F. (40° C.). As soon as pigment starts to ooze from the edges of the sandwich, peel off the pigment backing paper, keeping the support under the surface of the water	¼	60
38.	40¼	Move support about under water until all surplus pigment has been washed away from the colour relief	4¼	62
39.	44½	Immerse for about ½ minute in cold water to set the gelatine, blot back of transparent support, and put magenta relief to dry	½	62
40.	45	Immerse yellow image on its support in hot water at 105° F. (40° C.). As soon as pigment starts to ooze from the edges of the sandwich, peel off the pigment backing paper, keeping the support under the surface of the water	¼	60
41.	45¼	Move support about under water until all surplus pigment has been washed away from the colour relief	4¼	62
42.	49½	Immerse for about ½ minute in cold water to set the gelatine, blot back of transparent support, and put yellow relief to dry.	½	62

STAGE I (contd.)

Step	Time on Clock (Mins.)	Operation	Time Taken (Mins.)	See page
43.	50	Squeegee soluble temporary support on to another transparent support, and dry down	1½	68
44.	51½	Put bromide prints to wash for re-development (they can be redeveloped any time)	½	63
		Stage I : Total time taken :	82 *minutes*	

STAGE II : TRANSFER TO SOLUBLE TEMPORARY SUPPORT

Step	Time on Clock (Mins.)	Operation	Time Taken (Mins.)	See page
45.	0	Resoak soluble temporary support for about 2 minutes in water between 70° and 80° F. (21–27° C.)	2	68
46.	2	Immerse cyan image on transparent support, and bring into contact with soluble temporary support. Eliminate air bubbles. Remove sandwich from water and squeegee together	2	69
47.	4	Dry sandwich until the soluble temporary support with cyan image on it strips off from the transparent support	15 (forced drying)	69
47a.	19	If celluloid supports have been used, the surface of the cyan image must have the wax removed from it	5	72
48.	24	Resoak soluble temporary support with cyan image for about 1½–2½ minutes at 65–70° F. (18–21° C.) Immerse magenta relief on transparent support, and bring into rough register with cyan	3	72
49.	27	Remove sandwich from water and squeegee lightly. Register accurately	4	72
50.	31	Squeegee firmly, and dry down sandwich until soluble temporary support with cyan and magenta images strips off from the transparent support	20 (forced drying)	72

STAGE II (contd.)

Step	Time on Clock (Mins.)	Operation	Time Taken (Mins.)	See page
50a.	51	If celluloid supports have been used, the surface of the magenta image must have the wax removed from it	5	72
51.	56	Resoak soluble temporary support with cyan and magenta images for about 2½ minutes in water at 65–70° F. (18–21°C.). Immerse yellow relief on transparent support, and bring into rough register with the other two	3	72
52.	59	Remove sandwich from water and squeegee lightly. Register accurately	4	72
53.	63	Squeegee firmly, and dry down sandwich until soluble temporary support with the three images strips off from the transparent support	20 (forced drying)	72
53a.	83	If celluloid supports have been used, the surface of the yellow image must have the wax removed from it	5	72
		Stage II : Total time taken :	88 *minutes*	
		Actual working time :	32 *minutes*	

STAGE III : TRANSFER TO FINAL SUPPORT

Step	Time on Clock (Mins.)	Operation	Time Taken (Mins.)	See page
54.	0	Put final support to soak for about 10 minutes in water at 65–70° F. (18–21°C.)	10	74
55.	10	Trim picture on temporary support to required size	2	74
56.	12	Immerse picture in same dish of water as final support, and bring the two together. Squeegee	3	74
57.	15	Blot both sides of sandwich and allow to dry thoroughly	20 (forced drying)	74

STAGE III : TRANSFER TO FINAL SUPPORT

Step	Time on Clock (Mins.)	Operation	Time Taken (Mins.)	See page
58.	35	Soak sandwich for 10 minutes in water at 65–70° F. (18–21° C.)	10	74
59.	45	Transfer to warm water at 105° F. (40° C.) until soluble temporary support strips off. Wash away all surplus gelatine	5	76
60.	50	Put print into cold water for ½ minute to set gelatine, then hang up to dry	60 (minimum with fan)	76
		Stage III : Total time taken :	110 *minutes*	
		Actual working time :	10 *minutes*	

SINGLE BATH SENSITISER : SENSITISING AND FIRST SANDWICH

With the single bath sensitiser steps 2 to 21 are somewhat different. The subsequent procedure is, however, identical with that for the two-bath process.

Step	Time on Clock (Mins.)	Operation	Time Taken (Mins.)	See page
2s.	0	Set clock	—	
3s.	0	Take print from red filter negative out of the soaking water, and squeegee on to squeegee blanket	½	66
4s.	½	Cover print with water or buffer solution	½	66
5s.	1	Immerse cyan tissue for 2½ minutes in sensitiser	2½	66
6s.	3½	Remove tissue from solution, drain for 15–20 seconds, and lay on other half of squeegee blanket	½	66
7s.	4	Squeegee the two halves of squeegee blanket together	½	67
8s.	4½	Remove the sandwich, blot both sides, and put between wax paper to dry for 10 minutes under light pressure (e.g., a book)	½	67

SINGLE BATH SENSITISER (*contd.*)

Step	*Time on Clock (Mins.)*	*Operation*	*Time Taken (Mins.)*	*See page*
9s.	5	Take print from green filter negative out of soaking water and squeegee on to squeegee blanket	½	66
10s.	5½	Cover print with water or buffer solution	½	66
11s.	6	Immerse magenta tissue for 2½ minutes in sensitiser	2½	66
12s.	8½	Remove tissue from solution, drain for 15–20 seconds, and lay on other half of squeegee blanket	½	66
13s.	9	Squeegee the two halves of the squeegee blanket together	½	67
14s.	9½	Remove the sandwich, blot both sides, and put between wax paper to dry for 10 minutes under light pressure (e.g., a book)	½	67
15s.	10	Take print from blue filter negative out of soaking water and squeegee on to squeegee blanket	½	66
16s.	10½	Cover print with water or buffer solution	½	66
17s.	11	Immerse yellow tissue for 2½ minutes in sensitiser	2½	66
18s.	13½	Remove tissue from solution, drain for 15–20 seconds, and lay on other half of squeegee blanket	½	66
19s.	14	Squeegee the two halves of the squeegee blanket together	½	67
20s.	14½	Remove the sandwich, blot both sides, and put between wax paper to dry for 10 minutes under light pressure (e.g., a book)	½	67
21s.	15	Clear up work bench	3	
		SECOND SANDWICH		
22s. *et seq.*	18	Carry on as for two-bath process		94

DENSITOMETRY

The contrast and density of both negatives and bromide prints plays, as we have seen, an important part in making tricolour carbro prints. Mostly this can be assessed visually by examining and comparing the blackness of the various bromide prints and of the grey scales included in the picture.

However, for really accurate work, and particularly for standardised work, this is not enough ; both density and contrast measurements are needed.

The advanced amateur must therefore know something about densitometry.

NEGATIVE CONTRAST

Before discussing the measurement of contrast and density in a negative, it is important to have a clear idea of what these terms mean.

From a visual or photographic point of view any scene can be considered as composed of a very large number of small areas each reflecting different amounts of light. It is these differences of light intensity which are transmitted by the lens and form an image of the subject on the film or plate in a camera.

For an average scene out-of-doors the difference in the intensity of the light reflected from the lightest and darkest parts of a subject is about 100 to 1. This may be referred to as the contrast range of the subject.

It will simplify the problem if we consider the whole subject as being composed of only these two extreme areas.

The light which is reflected from these areas will pass through the lens and form two corresponding patches of light on the sensitive material in the camera. Owing to the dispersion of light which occurs in the lens and the light reflection inside the camera body, the contrast between the two areas will be less than it was in the original subject.

If a plate is now exposed in the camera and developed, the two light patches will be represented by areas of different density, the difference between the two densities being a measure of the contrast produced by the plate under these conditions.

In order to obtain a uniform standard of comparison, the *difference* in the intensity of the light which can pass through the light and dark patches of the negative can be measured and compared with the *difference* of intensity between the light which fell upon those two areas when the exposure was made. This comparison is made on a logarithmic basis.

To take a concrete example let us suppose that the intensity of light reaching one half of the plate was 100 times that in the other. After the plate was developed, the transmissions of the two halves were measured and it was found that the lightest part transmitted 10 times as much light as the darker half.

The contrast of the negative and of the original image is then compared as the logarithmic ratio between these two. In this case :

$$\frac{Log\ 10}{Log\ 100} = \frac{1}{2}$$

This ratio is always denoted by the symbol γ (pronounced gamma). It depends mainly on the characteristics of the sensitive material, and on the developer and development time.

Unless a subject includes some standard reference object, or is made under controlled conditions, there is

no possible means of measuring the contrast to which the negative has been developed. Although it is of course possible to estimate this from previous experience with similar types of subject.

The inclusion of a grey scale in the subject does not completely solve the problem. The difference in the intensity of the light reflected from the steps can be measured, but is apt to vary according to the angle at which the light strikes them. The flare factor of the lens has also to be taken into account, as the contrast of the image formed by the lens will be less than that of the original subject. Calculation of negative gamma (p. 112) obtained by this method does not therefore usually provide a very reliable standard for comparison.

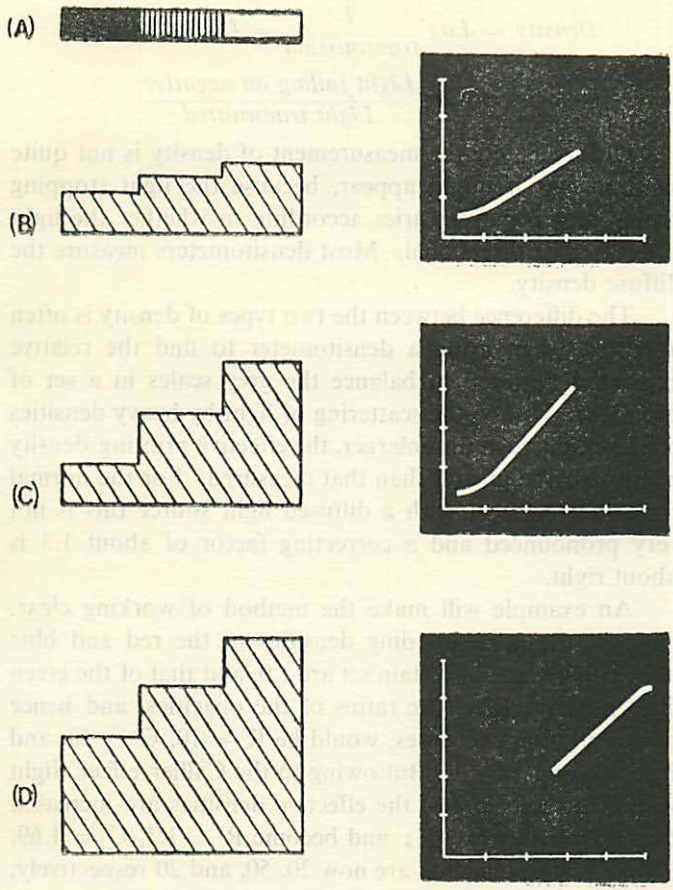
For this reason if the gamma produced by a plate under certain conditions of processing is to be measured, it is normally exposed under a step wedge. This may take the form of a negative with steps of different density. By measuring these densities the differences in the intensity of light which will reach the plate can be calculated.

MEASUREMENT OF OVER-ALL DENSITY

The extent to which a negative obstructs the passage of light may be measured by comparing the amount of light falling on the negative with that transmitted by it on the other side. The ratio of these two, which will always be greater than unity, is called the opacity of the negative.

We can also express this in another way by considering what proportion of the light is actually transmitted. This is known as the transmission of the negative. For many purposes it is convenient to use a logarithmic scale for measuring the light obstructing power of a negative.

The logarithm of opacity is known as density. Mathematically the relationship between these three terms is :



Practical gamma. The vertical heights of the steps in B, C, and D represent the densities in the negatives corresponding to the three steps of the simplified grey scale A. The relative difference in the height of the steps is a measure of the gamma. The absolute height of the steps depends on the exposure. Thus the gamma of C and D is the same, though the exposure was greater in D. The gamma in B is lower. If the density of the steps is plotted against the logarithm of the exposure (i.e. the logarithm of transmission of the grey scale steps), the slope of the curve again measures the gamma (see also p. 112).

$$Density = Log \frac{1}{transmission} = Log\ opacity$$

$$= Log \frac{Light\ falling\ on\ negative}{Light\ transmitted}$$

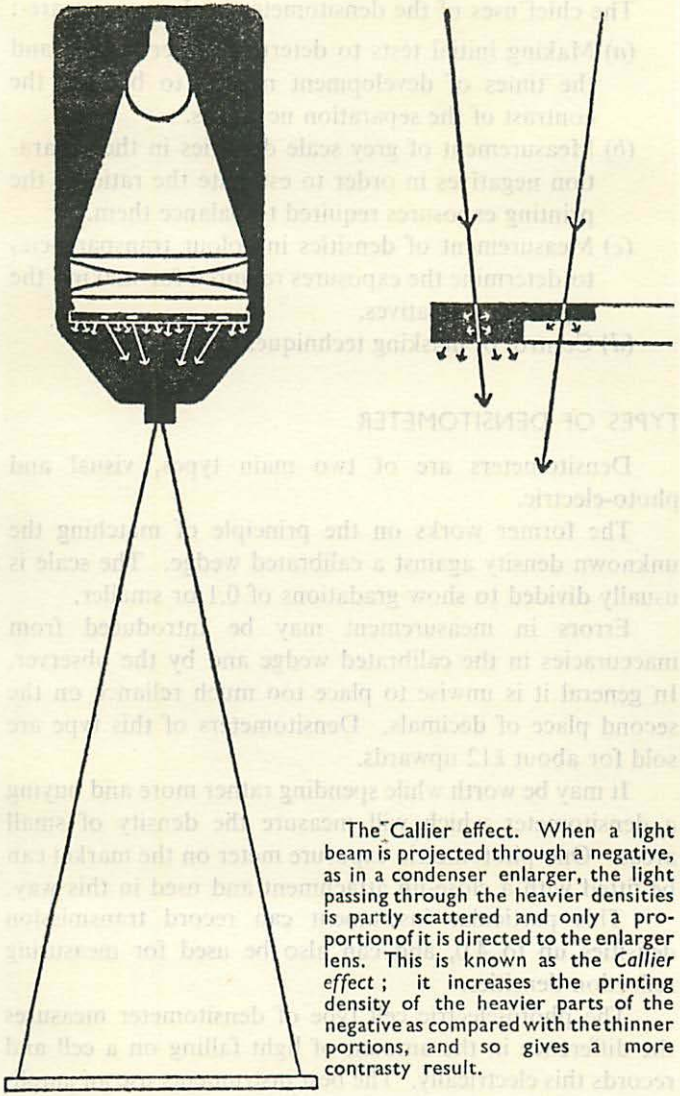
Unfortunately the measurement of density is not quite as simple as it might appear, because the light stopping power of a negative varies according to whether the light is diffused or directional. Most densitometers measure the diffuse density.

The difference between the two types of density is often apparent when using a densitometer to find the relative exposures required to balance the grey scales in a set of bromides. Due to the scattering of light by heavy densities of the negative in the enlarger, the effective printing density will usually be greater than that measured. For the normal condenser enlarger with a diffused light source this is not very pronounced and a correcting factor of about 1.3 is about right.

An example will make the method of working clear. Suppose the corresponding densities of the red and blue filter negatives of a certain set are 1.0, and that of the green filter negative 1.3. The ratios of the opacities, and hence of the printing exposures, would be R = 10, G = 20, and B = 10, or 1 : 2 : 1. But owing to the Callier effect (light scatter in the enlarger) the effective densities are increased by a factor of, say, 1.3 ; and become R = 1.3, G = 1.69, B = 1.3. The opacities are now 20, 50, and 20 respectively, and the ratio of the printing exposures 1 : 2½ : 1.

USE OF A DENSITOMETER

Although a densitometer is not essential for making colour prints from direct separation negatives, it is very useful. When masking either transparencies or separation negatives it becomes almost a necessity.



The Callier effect. When a light beam is projected through a negative, as in a condenser enlarger, the light passing through the heavier densities is partly scattered and only a proportion of it is directed to the enlarger lens. This is known as the *Callier effect*; it increases the printing density of the heavier parts of the negative as compared with the thinner portions, and so gives a more contrasty result.

The chief uses of the densitometer in the process are :

(*a*) Making initial tests to determine filter factors and the times of development needed to balance the contrast of the separation negatives.

(*b*) Measurement of grey scale densities in the separation negatives in order to estimate the ratio of the printing exposures required to balance them.

(*c*) Measurement of densities in colour transparencies to determine the exposures required for making the separation negatives.

(*d*) Control of masking technique.

TYPES OF DENSITOMETER

Densitometers are of two main types, visual and photo-electric.

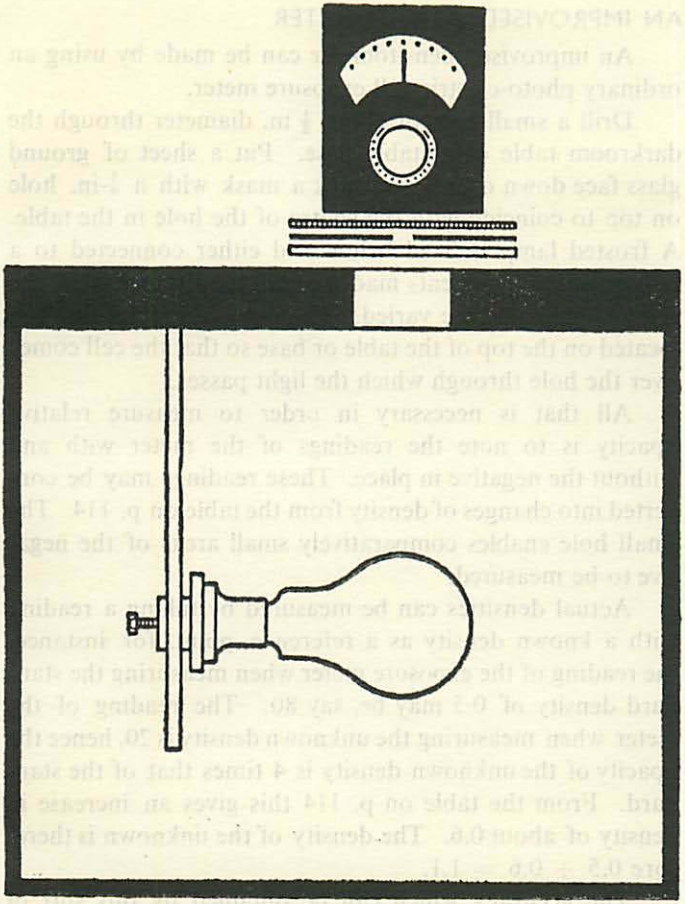
The former works on the principle of matching the unknown density against a calibrated wedge. The scale is usually divided to show gradations of 0.1 or smaller.

Errors in measurement may be introduced from inaccuracies in the calibrated wedge and by the observer. In general it is unwise to place too much reliance on the second place of decimals. Densitometers of this type are sold for about £12 upwards.

It may be worth while spending rather more and buying a densitometer which will measure the density of small areas. One photometric exposure meter on the market can be fitted with a close-up attachment and used in this way.

This particular instrument can record transmission densities up to 4.0, and can also be used for measuring reflection densities.

The photo-electric cell type of densitometer measures the difference in the amount of light falling on a cell and records this electrically. The best instruments use an amplifying circuit and are very expensive.



Layout for home-made densitometer. The lamp is mounted under a $\frac{1}{2}$-in. hole in the top of the box, and its distance is adjustable so as to obtain a convenient brightness level. Above the hole there is a ground glass or opal glass screen, and a mask with a hole about $\frac{1}{8}$ in. The part of the negative to be measured is then placed directly above the hole in the mask.
Readings are taken with the exposure meter and compared with the reading obtained without the negative in position (p. 108).

AN IMPROVISED DENSITOMETER

An improvised densitometer can be made by using an ordinary photo-electric cell exposure meter.

Drill a small hole of about $\frac{1}{2}$ in. diameter through the darkroom table or suitable base. Put a sheet of ground glass face down over it and stick a mask with a $\frac{1}{8}$-in. hole on top to coincide with the centre of the hole in the table. A frosted lamp is fixed below and either connected to a reostat or arrangements made so that its distance from the ground glass may be varied. The exposure meter is then located on the top of the table or base so that the cell comes over the hole through which the light passes.

All that is necessary in order to measure relative opacity is to note the readings of the meter with and without the negative in place. These readings may be converted into changes of density from the table on p. 114. The small hole enables comparatively small areas of the negative to be measured.

Actual densities can be measured by taking a reading with a known density as a reference point, for instance, the reading of the exposure meter when measuring the standard density of 0·5 may be, say 80. The reading of the meter when measuring the unknown density is 20, hence the opacity of the unknown density is 4 times that of the standard. From the table on p. 114 this gives an increase in density of about 0.6. The density of the unknown is therefore $0.5 + 0.6 = 1.1$.

The accuracy which can be obtained by this sort of measuring instrument depends of course on the meter itself. If the meter is examined it will be found that the distance between the scale divisions varies over the range. The strength or distance of the light should therefore be adjusted, so that the meter readings fall on the widest part of the scale. For this reason the standard density should also be as close as possible to that being measured. The exposure

negative of the *Focal Enlarging Chart* is very useful for this purpose.

THE CHARACTERISTIC CURVE

In order to show the relationship between the exposure given to a negative and the density produced, it is convenient to plot this in the form of a graph which is usually referred to as the *characteristic curve* of the negative (p. 110).

The negative densities are plotted on the vertical axis and the relative log exposures on the horizontal axis.

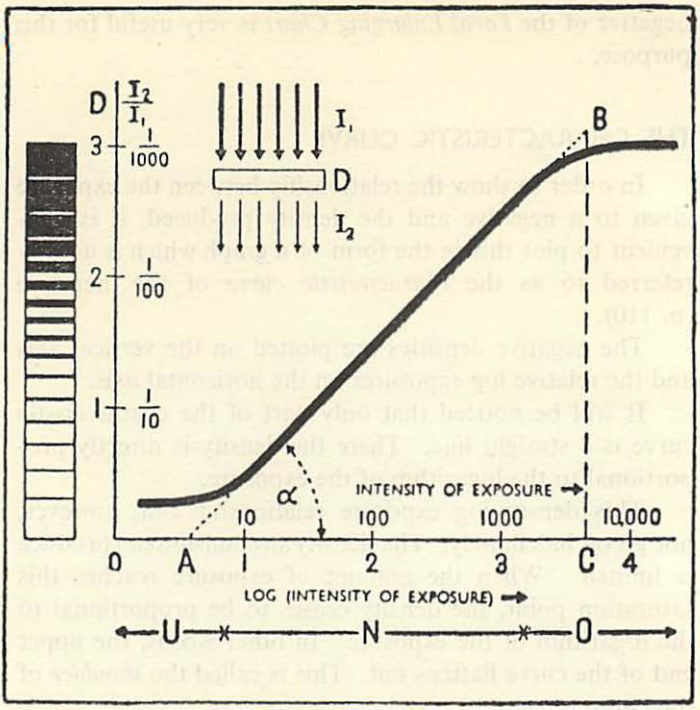
It will be noticed that only part of the characteristic curve is a straight line. There the density is directly proportional to the logarithm of the exposure.

This density-log exposure relationship can, however, not go on indefinitely. The density an emulsion can produce is limited. When the amount of exposure reaches this saturation point, the density ceases to be proportional to the logarithm of the exposure. In other words, the upper end of the curve flattens out. This is called the *shoulder* of the curve.

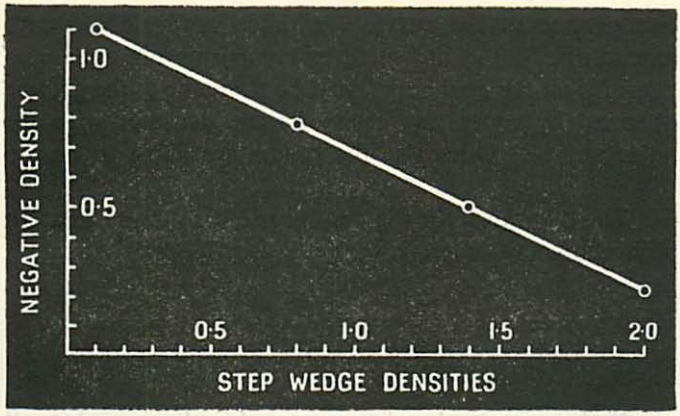
There is also a certain minimum exposure which is required to produce any image at all. The density-log exposure relationship does not apply in the neighbourhood of this minimum exposure, either. Therefore the lower end of the curve also flattens out. This is called the *toe* of the curve.

Moreover, the curve does not even start at the zero density level, but nearly always a little higher up. This is due to an initial density produced by the emulsion even without exposure. It is called the *fog density*.

These three factors should therefore be allowed for when deducing data from densitometric measurements. Such measurements must always be taken from the *straight-*

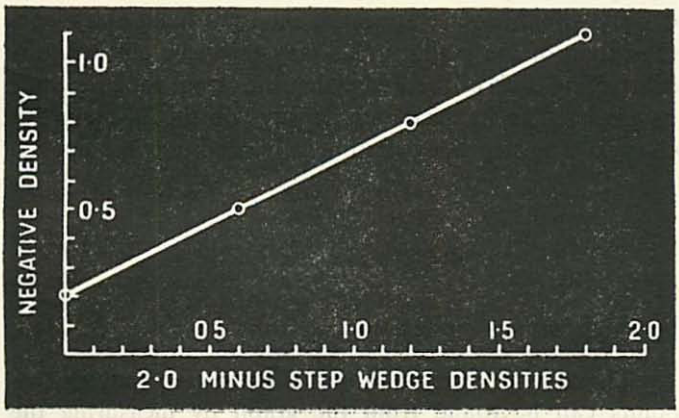


The characteristic curve and the gamma. The characteristic curve of photographic material is a plot of density against the logarithm of exposure necessary to produce that density on development. Density is defined as the logarithm of the incident divided by the transmitted light intensity ; D—log I_1/I_2, I_1 and I_2 being the intensities illustrated in the insert diagram. The values of the ratio of I_2/I_2 are shown against the density values D, and similarly the exposure intensity values are shown against the log exposure in order to illustrate the logarithmic relationships. The region of under-exposure is indicated by U, that of normal exposure by N, that of over-exposure by O, along the exposure axis. Gamma is measured or determined by extending the straight line part of the curve until it meets the horizontal axis at A and a vertical axis erected at a point B, anywhere along the exposure axis. Then gamma is tan α = BC/AC — γ. In the above example gamma is 1, for the angle α is 45 deg. and so AC and BC are equal. (From *Developing* by C. I. Jacobson).



Above : Plotting the negative densities against the step wedge densities will give an approximate characteristic curve. It will, however, slope in the wrong direction ; towards the right instead of towards the origin of the ordinates. This is because the smaller the step wedge density, the greater the exposure.

Below : To plot the negative density against the equivalent of the log. exposure, the step wedge densities are subtracted from a constant equal to, or greater than, the maximum density (in this case 2.0). That then produces a graph sloping in the right direction. From it the gamma can be read off ; in this case 0.5 (p. 112).



line portion of the curve. In other words, the overall gamma (p. 101) as measured by comparing two separated densities on the grey scale, must be the same as the gamma obtained by comparing each of these densities with the adjacent one. Otherwise the results are liable to be too low.

The allowance for fog density is not so important. In all but the most exacting work it is usually small enough to be ignored.

PLOTTING THE CURVE

If the negative has been exposed under a wedge, all we need to do in order to plot the graph is to measure the densities of each step of the wedge and those of the corresponding steps in the negative. These might be as follows :

Step Wedge	2.0	1.4	0.8	0.2
Negative	0.2	0.5	0.8	1.1

Now the actual exposure given to the plate will be least when the density of the step wedge is a maximum and if the figures are plotted as they stand, the smallest step wedge density would have to appear at the right hand away from the origin of the graph. This may easily be corrected by subtracting each of the wedge densities from a figure equal or greater than its maximum density. In this instance 2 is chosen. The step wedge and negative densities become :

Step	(1)	(2)	(3)	(4)
Step Wedge	0.0	0.6	1.2	1.8
Negative	0.2	0.5	0.8	1.1

MEASUREMENT OF GAMMA

The average contrast or γ of the negative between two points can be found from the graph by measuring the

distance between these points on the vertical axis and dividing by the distance between the same two points on the horizontal axis.

Alternatively gamma can be calculated direct from the figures by taking the difference in density between any two steps in the negative and dividing by the corresponding density difference in the step wedge, e.g., average gamma between steps 3 and 4 =

$$\frac{1.1 - 0.8}{1.8 - 1.2} = \frac{0.3}{0.6} = 0.5$$

Another way of obtaining the gamma of a negative is to give it a series of known exposures and then measure the differences in density produced. The method has its limitations as the failure of the reciprocity law (p. 124) may affect the result if the ratio between the maximum and minimum exposure is more than 3 or 4 times.

This principle can be adapted for use when making exposures with a camera by giving two exposures of known duration and then measuring the difference in density of the negatives. For example, two negatives were exposed for 15 and 60 seconds respectively, and the difference in density of some object recorded on the negatives was found to be 0.45.

The ratios of the exposures was $\frac{60}{15} = 4$.

Hence log exposure = 0.6.

$$Gamma = \frac{Density}{Log\ Exposure} = \frac{0.45}{0.6} = 0.75$$

DENSITOMETRY CONVERSION TABLE

Density	*Trans-mission*	*Opacity*	*Density*	*Trans-mission*	*Opacity*
.02	.955	1.05	.76	.174	5.76
.04	.912	1.10	.78	.166	6.03
.06	.871	1.15	.80	.158	6.31
.08	.832	1.20	.82	.151	6.61
.10	.794	1.25	.84	.144	6.92
.12	.759	1.31	.86	.138	7.25
.14	.725	1.38	.88	.132	7.59
.16	.692	1.45	.90	.126	7.94
.18	.661	1.51	.92	.120	8.32
.20	.631	1.58	.94	.115	8.71
.22	.602	1.66	.96	.110	9.12
.24	.575	1.74	.98	.105	9.55
.26	.549	1.82	1.00	.100	10.0
.28	.525	1.91	1.02	.096	10.5
.30	.501	2.00	1.04	.091	11.0
.32	.478	2.09	1.06	.087	11.5
.34	.457	2.18	1.08	.083	12.0
.36	.436	2.29	1.10	.079	12.5
.38	.417	2.40	1.12	.076	13.1
.40	.398	2.51	1.14	.072	13.8
.42	.380	2.63	1.16	.069	14.5
.44	.363	2.75	1.18	.066	15.1
.46	.347	2.88	1.20	.063	15.8
.48	.331	3.02	1.22	.060	16.6
.50	.316	3.16	1.24	.058	17.4
.52	.302	3.31	1.26	.055	18.2
.54	.288	3.47	1.28	.053	19.1
.56	.275	3.63	1.30	.050	20.0
.58	.263	3.80	1.32	.048	20.9
.60	.251	3.98	1.34	.046	21.8
.62	.240	4.17	1.36	.044	22.9
.64	.229	4.37	1.38	.042	24.0
.66	.219	4.57	1.40	.040	25.1
.68	.209	4.79	1.42	.038	26.3
.70	.200	5.01	1.44	.036	27.5
.72	.191	5.25	1.46	.035	28.8
.74	.182	5.50	1.48	.033	30.2

DENSITOMETRY CONVERSION TABLE

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1.50	.032	31.6	2.26	.0055	182
1.52	.0302	33.1	2.28	.0053	191
1.54	.0288	34.7	2.30	.0050	200
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1.64	.0229	43.7	2.40	.0040	251
1.66	.0219	45.7	2.42	.0038	263
1.68	.0209	47.9	2.44	.0036	275
1.70	.0200	50.1	2.46	.0035	288
1.72	.0191	52.5	2.48	.0033	302
1.74	.0182	55.0	2.50	.0032	316
1.76	.0174	57.6	2.52	.0030	331
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2.04	.0091	110	2.80	.0016	631
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1.88	.0132	75.9	2.64	.0023	437
1.90	.0126	79.4	2.66	.0022	457
1.92	.0120	83.2	2.68	.0021	479
1.94	.0115	87.1	2.70	.0020	501
1.96	.0110	91.2	2.72	.0019	525
1.98	.0105	95.5	2.74	.0018	550
2.00	.0100	100.0	2.76	.0017	576
2.02	.0096	105	2.78	.0017	603
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.40	.398	2.51	1.14	.072	13.8
.42	.380	2.63	1.16	.069	14.5
.44	.363	2.75	1.18	.066	15.1
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.48	.331	3.02	1.22	.060	16.6
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.60	.251	3.98	1.34	.046	21.8
.62	.240	4.17	1.36	.044	22.9
.64	.229	4.37	1.38	.042	24.0
.66	.219	4.57	1.40	.040	25.1
.68	.209	4.79	1.42	.038	26.3
.70	.200	5.01	1.44	.036	27.5
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1.78	.0166	60.3	2.54	.0029	347
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1.82	.0151	66.1	2.58	.0026	380
1.84	.0144	69.2	2.60	.0025	398
1.86	.0138	72.5	2.62	.0024	417
1.88	.0132	75.9	2.64	.0023	437
1.90	.0126	79.4	2.66	.0022	457
1.92	.0120	83.2	2.68	.0021	479
1.94	.0115	87.1	2.70	.0020	501
1.96	.0110	91.2	2.72	.0019	525
1.98	.0105	95.5	2.74	.0018	550
2.00	.0100	100.0	2.76	.0017	576
2.02	.0096	105	2.78	.0017	603
2.04	.0091	110	2.80	.0016	631
2.06	.0087	115	2.82	.0015	661
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STANDARDISATION

The number of factors which affect the results obtained by the carbro process are many. Complete control of all the variables is only possible under something approaching laboratory conditions. For most practical purposes, it is enough to know what are the most likely causes of variation, and to avoid them as far as possible. The following is therefore a summary of most of the variables.

MATERIALS.—Different batches of negative materials, and also bromide papers and pigment papers vary in their characteristics. The time and conditions of storage also have their effect.

With negative materials the gamma and speed, and also the filter factors may change (p. 122). It is therefore advisable to stick to one batch of negative material for one job, and make fresh tests of each new batch or after long storage.

Similarly with bromide and pigment papers the safest course is not to change from one batch to another if accurate results are required (p. 125).

ENLARGER ILLUMINATION.—Voltage fluctuations of the electric supply will affect the enlarger exposures (p. 34). For most accurate work some sort of voltage control is an advantage (p. 34).

Also, the intensity of illumination slowly decreases as the enlarger bulb gets old. While this is of no consequence during the normal course of work, where fresh tests are made for each set of bromide prints (p. 29), the enlarger

bulb should not be changed in the middle of the work. If it should burn out, the exposure tests have to be repeated.

Further, the illumination on the enlarger baseboard is never quite even (p. 33). The negatives and bromide paper should therefore always be in the same position in the carrier and baseboard respectively (p. 34).

DEVELOPMENT OF BROMIDES.—Development conditions for the three bromides must be standardised (See p. 35). If several sets of bromides are being made a good method of eliminating possible variations is to make the three exposures on one long strip of bromide paper or to tape the three sheets together and develop them at the same time in a large dish.

THE SENSITISER.—Apart from the sensitiser formulae themselves, one of the greatest variables is the acidity or pH value of the solution (p. 45). Here accurate control is needed for consistent work.

Also, the amount of sensitiser used per unit area of pigment paper should be standardised (p. 44).

SOAKING THE BROMIDES.—The pH of the soaking bath should be kept constant. This is best achieved by the use of buffer solutions (p. 52).

THE TIMETABLE.—It is highly desirable that the timetable decided for the process be carefully followed. Certain operations are, however, more sensitive than others.

With two-bath sensitising the effective immersion time (i.e., including the draining time) in the second bath is vital (p. 56). The time of immersion in the first bath is not so critical.

With single bath sensitising a minimum immersion time of 2 minutes (p. 66) is needed. Immersion in excess of this produces only slight variations.

In the first sandwich (p. 59) maximum bleaching normally occurs in 5–8 minutes. Times over this figure have only a very slight effect, and are roughly equivalent

to an increased drying down time in the second sandwich.

In the second sandwich (p. 60) an increased period of contact produces a darker print. This is also affected by the amount of drying down which takes place. If the sandwich is fully protected by grease-proof paper, the difference in density produced between 10 and 25 minutes of contact is not likely to be equivalent to more than about 10 per cent increase in the exposure of the bromide prints.

WORKING CONDITIONS.—The only two variables are temperature and humidity.

It is, of course, desirable to maintain the temperature of the working room as near to that of the solutions as possible. Slight changes in temperature which occur in the sensitiser between sensitising the three pigments are unlikely to be important. In general the higher the temperature of the sensitising solution, the greater the contrast produced.

While professional studios very often standardise the humidity, this is only important in so far as it affects the drying down of the first and second sandwiches, and the condition of the pigment papers before sensitising. If these are very dry they do not absorb the sensitiser quite so easily. Under the normal climatic conditions in England this factor need not cause serious concern.

EVEN DEVELOPMENT OF NEGATIVES.—Uneven development is a trouble which quite often becomes noticeable in monochrome work. When it is realised that the eye is at least four times more sensitive to changes in colour, the importance of securing reasonably even development is obvious.

To ensure it, three conditions must be fulfilled :

(*a*) The layer of developer which adheres to the surface of the negative must be completely removed at frequent intervals.

(*b*) The average rate of flow of developer over the emulsion surface should be the same at all points.

(*c*) The developer coming into contact with the plate should be homogeneous. This means that the developer leaving the surface of the plate should be intimately mixed with the rest of the solution.

If these requirements can be satisfied, it is possible to develop a negative so that the variations in density do not exceed 2 per cent. In practice the errors introduced by variations in sensitivity of the emulsion or coating thickness can cause density differences about three times as great, and a lower standard of accuracy for development can be accepted.

When only one set of negatives need be developed at a time, the brush method is the most efficient. A simple arrangement is to cut windows in a sheet of hard rubber, so that the plates will lie flat with their surfaces $\frac{3}{4}$ to 1 mm. (not more) below the surface of the rubber. A flat bladed squeegee can then be pushed continually up and down the dish during development without danger of scratching the negatives.

Tank development is not as effective as the brush method, but can give perfectly satisfactory results. In practice one of the best methods of agitation is to lift the negatives out of the tank 8 to 10 times during development, drain for 5 seconds and then replace them in the tank with a minimum disturbance of the developer.

One way of testing the effectiveness of the method of development used is to fog a plate perfectly evenly so as to give an over-all density of about 0.4 and then to give it a long exposure through an opaque mask containing a number of small holes about 2 mm. in diameter. Any unevenness in development will show itself by a " streamer " of lighter density coming from the heavily exposed dots.

VARIATIONS IN NEGATIVE GAMMA

As mentioned on p. 22, negative material seldom produces equal contrast when exposed through the three

tricolour filters. In order to obtain a set of negatives which are balanced, different development times have to be given. The extent to which this defect is present varies with the batch of material and is also affected by the characteristics of the filters in use, the type and concentration of developer and degree of agitation employed.

The only scientific method of arriving at the correct development times is to plot gamma development time curves and to read off the development times required to produce the selected gamma. This involves making at least four wedge exposures through each of the filters and developing these for different times. The density obtained for any given exposure will of course vary with the development time. In order that the same density range can be covered, the wedges used for exposing the negatives should contain a fair number of steps. Separate density log exposure graphs are then plotted for each development time of each filter negative and from these the gamma time curves may be deduced.

The above procedure besides being lengthy, requires very accurate control to obtain worth-while results. For this reason it is suggested that the worker should be content to obtain his development times and filter factors by the method of successive approximation described below.

Four negatives should be exposed respectively through each of the tricolour filters and one without a filter. The exposures may be made either in the camera with a grey scale as the reference object, or under a wedge which is illuminated with light filtered through each of the tricolour filters in turn. The latter method has the advantage that the gamma of the negatives at any part of the characteristic curve can very easily be obtained. Only the values from the straight-line portion are, of course, usable (p. 109).

If daylight filter factors are required, the wedge may be inserted in the back of a camera and each plate exposed

behind it. The filters are put on the camera lens, which should be lined up on a sheet of white blotting paper when exposing.

To obtain gammas when using a grey scale, either the brightness range between the steps must be measured (and lens flare taken into account) or else a fifth negative taken, giving exactly two or three times the exposure of one of the other ones. If the exposure is increased by a larger factor, reciprocity failure (p. 124) may affect the result. From density measurements on these two negatives, the gamma can be found and the effective brightness range between each step of the grey scale calculated.

The filter factors for the new batch of material are of course still unknown, but for purposes of the test they can be estimated with sufficient accuracy from previous experience or from the makers' recommendations.

After the three negatives have been developed and dried, measure the density of two corresponding steps in each of the negatives. These should be as widely separated as possible, but should avoid the toe or shoulder of the characteristic curve. Densities round about 0.5 and 1.00 are suitable. Tabulate these in the form shown below :

	Red Filter	*Green Filter*	*Blue Filter*	*No Filter*
1st Step	0.5	0.58	0.4	0.6
2nd Step	1.3	1.38	1.0	1.4

The differences in the actual densities of the steps may be due to variations in contrast or to incorrect filter factors but the density *difference* between the steps will be proportional to the negative gamma. In the example the differences are :

Red filter negative : 1.3 − 0.5 = 0.8
Green filter negative : 1.38 − .58 = 0.8
Blue filter negative : 1.0 − 0.4 = 0.6

It will be seen that for the red and green filter negatives the differences are the same and equal to 0.8 while that of the blue is only 0.6. This means that the contrast of the blue filter negative is too low and that it must receive extra development time.

If the negatives were exposed under a step wedge, the density difference between the steps can easily be measured. Assuming this difference to be 1.0, the gamma of the red and blue filter negatives will be $\frac{0.8}{1.0} = 0.8$ and that of the blue $\frac{0.6}{1.0} = 0.6$. If a gamma development time curve for the material and developer is available, it is usually possible by interpolation to make a very fair estimate of the increase of development time necessary to bring the negatives into balance.

CORRECTING THE FILTER FACTORS

If as in the above example, the development time of one of the negatives has to be increased, it will considerably increase the density of the middle tones of the negative (due chiefly to increase in contrast) and also slightly increase its speed. This will in turn affect the filter factors (p. 119).

We may, however, correct the filter factors for the old development times and make allowances for the changes we are going to make. Using the same figures as in the last example, we have :

	Red Filter	*Green Filter*	*Blue Filter*	*No Filter*
1st Step	0.5	0.58	0.4	0.6

The differences in density between each of the filter negatives and the no filter negative are 0.1, 0.02 and 0.2.

Now if the filter factors had been correct, all negatives

would have the same density. From the characteristic curve (p. 110) a density difference D corresponds to a difference in the log exposure of D/gamma. Hence the filter factors must be adjusted by multiplying them by the opacity (antilog) of D/gamma, if the density was less than that of the no filter negative. If the density of the filter negative was greater, *divide* the filter factor by the opacity of D/gamma. In the above example, with a gamma of 0.6, a blue filter factor of, say, 10 becomes 10 × antilog (0.2/0.6) = 21.5.

But as the blue filter negative will have to receive extra development to increase its gamma from 0.6 to 0.8, its effective density will be increased (p. 119). To make allowance for *both* variables multiply the *old* filter factor by the antilog of $\left(\frac{d_1}{\gamma_1} - \frac{d_2}{\gamma_2}\right)$

where d_1 = *Density of negative to be matched*
d_2 = *Density of negative requiring correction*
γ_1 = *Gamma of negative to be matched*
γ_2 = *Gamma of negative requiring correction.*

The filter factor for the blue filter negative would therefore be $10 \times \text{antilog} \left(\frac{0.6}{0.8} - \frac{0.4}{0.6}\right) = 12$

After making these calculations, the test may be repeated using the new filter factors and times of development, and it should then be possible to produce a result which is near enough in practice.

For most purposes it is the ratio between the filter factors and not their actual values which matter. If the worker wishes to economise in material and save time, he may leave out the no filter negative and calculate the filter factors taking the green as the criterion. As the factor for this seldom varies very much it may be obtained from the

makers' list. At the very worst this method will only necessitate making a very small alteration to the normal speed of the plate when calculating exposures.

FAILURE OF THE RECIPROCITY LAW

The reciprocity law states that the photographic effect of light is proportional to the light intensity and to the time for which it acts.

This is only true over a small time range usually round about 1 second exposure. It is quite possible that if the lens is stopped down and the exposure increased to say 8 minutes, several times the calculated exposure will be needed to produce the same result.

This may have a quite important effect on the filter factors. For example, in a test on a well-known make of fast plate, it was found that if the unfiltered exposures in half watt light were around $\frac{1}{10}$ second, the filter factors were red = $2\frac{1}{2}$, green = $9\frac{1}{2}$, blue = 20. When the amount of light was reduced and the corresponding unfiltered exposure increased to 10 seconds, the factors became red = $2\frac{3}{4}$, green = 20, blue = 55.

If the time of exposure for each filter is fixed and the intensity of the light is varied (as would be the case if the lens stop was altered or the negatives exposed for the same time under a step wedge), the filter factors remain constant and are often referred to as the *intensity factors*. For exposures around 1 second, there is usually not much difference between the time and intensity factors. From a practical point of view any tests made to find filter factors should be made under roughly the same conditions of exposure as those in which they will be used.

The worker may well feel that the whole problem is rather beyond him, but he should remember that good prints can be made from negatives which are out of balance

in contrast by making adjustments later in the process. It is sometimes possible to get away with an error in the filter factors of as much as 100 per cent, if the exposure of the negatives is on the straight-line part of the characteristic curve (p. 109).

VARIATIONS IN THE PIGMENT PAPERS

Different batches of tricolour pigment papers are apt to vary slightly in the density and contrast which they will produce under given conditions. This of course applies as between the three colour pigments.

Variations in density can easily be compensated for by altering the relative exposures given to the bromide prints, and the maximum adjustment required for a medium grade of paper is not likely to exceed 10 per cent either way.

Differences in contrast are not quite so easily dealt with, the only entirely satisfactory method is to adjust the development times of the separation negatives to fit the characteristics of the pigments papers in use. For this reason batches of pigment paper are normally sold matched in their contrast characteristics, and the only precaution to observe is to avoid mixing pigment paper bought at different times.

BALANCE FACTORS

If the pigments are not in balance, sooner or later some conscious allowance will have to be made for the fact, as a correct print cannot be produced with unbalanced pigments even if the grey scales of the bromides are balanced.

Far the wisest plan is to make tests at the start. This may be done either by trial and error while making a print, or by a specific test with wedges.

The trial and error method is the one most likely to

appeal to the worker who has only a small stock of pigment paper, or who dislikes spending time on work which is not directly productive. The only requirements are a set of separation negatives balanced in contrast with a clear grey scale. From these a colour print is made, taking particular care that the grey scales of the bromides are accurately balanced. The finished print and its grey scale are examined, and if necessary another print made, adjusting the relative exposures of the bromides to overcome the errors in colour rendering.

Once a satisfactory print has been achieved, the degree to which the pigments are out of balance can be judged by referring to the percentage alterations which have been made between the exposures of the first and last set of bromides. When dealing with a print on which all the exposures have been altered proportionately, (so as to make it lighter or darker) these alterations must be discounted in calculating the percentages.

The following example makes this clear :

EXPOSURE ADJUSTMENTS

	Seconds		
	Cyan	*Magenta*	*Yellow*
1. Exposures required to balance grey scale in first set of bromides	100	130	110
2. Estimating that 10 per cent increase in exposure is needed to produce a darker print, exposures will be	110	143	121
3. Estimating that cyan should be reduced by 5 per cent and magenta increased by 3 per cent, exposures for second set of bromides will be	104½	147	121

Assuming the last print is satisfactory, the out-of-balance factors are as at 3 above, i.e., compared with the yellow, the cyan is 5 per cent too strong and the magenta 3 per cent too weak.

For the test wedge method three strips of bromide paper are needed, each with identical graded densities. These may be made either by printing through a wedge, or by the normal test-strip method of giving graded exposures to a sheet of bromide paper, which can then be cut into three parts.

If the balance and contrast of the pigment paper is to be tested over the whole normal range, a wedge is practically essential. This should have a density range of about 1.2 with a density increase between steps of 0.02, which corresponds to a 5 per cent increase in exposure of the bromide paper. Alternatively a continuous wedge which has a uniformly increasing density throughout its length may be used. If the wedge is wide enough, the three strips can be made with one printing. Otherwise each strip must receive precisely the same exposure and be developed and fixed at the same time.

For most purposes it will be sufficient to test the pigment paper over a narrow range. The bromide wedges can be prepared by giving a series of step exposures to the paper with the illumination adjusted to produce a medium grey tone with a fairly long exposure. A suitable series of exposures giving approximately a 5 per cent increase would be 200, 210, 220, 230, 240 seconds. This series is not mathematically correct as an increase of 5 per cent on 230 is not the same as 5 per cent on 200, but for practical purposes the fractions of a second may be ignored.

The increase in density between the steps on the bromide print will be too small to detect visually. In order to be able to identify them a cut out mask can be put over the paper when exposing it.

One major problem is that of securing even illumination when making the exposures, as otherwise the test will be worse than useless. If a small electric bulb is used, the paper must be in a direct line with it and at sufficient distance for

the edge of the paper not to be appreciably further away from the light than the middle. Reflections from the walls of the room must also be considered.

One solution is to use the enlarger as the light source and to put a sheet of ground glass over the lens which must be in a direct line with the middle of the paper. When the test strips are ready the three colour reliefs are made from them. After the first sandwich stage, they are transferred to strips of very thin unwaxed celluloid, developed and dried. For the most accurate work with a single bath sensitiser the three colours should be processed at the same time and may be transferred on to one large sheet of celluloid before development.

The colour wedges are resoaked for a minute or two in water. They are then superimposed and moved relative to each other until a pure grey is obtained. The relative displacement necessary to produce this will show how much the pigments are out of balance.

As an example, taking the middle step of the cyan as the reference, with the lightest part of the wedges to the left, it was found that in the balanced position, the magenta had to be moved two steps to the right, and the yellow one step to the left.

As the difference between each step was equivalent to a 5 per cent alteration in exposure of the bromide print, the magenta is 2×5 per cent $= 10$ per cent too strong. Similarly the yellow is 5 per cent too weak.

The purpose of wetting the strips before superimposing them is to cut out the reflections from the celluloid surfaces. Even then it is quite difficult to decide when a perfect grey has been obtained.

IMPURITY OF COLOURS

Most colours which occur in nature are impure. If considered in relation to spectrum colours, this is due to :

(*a*) The colour is not perfectly reflective and in effect has a proportion of black mixed with it. Its *luminosity* is decreased.

(*b*) The colour pigment allows some white light to be reflected and so becomes diluted or *desaturated.*

(*c*) The colour pigment reflects some light of one or more other colours ; its *hue* is altered.

When reproducing a colour we have therefore three factors to consider—the hue, luminosity and saturation.

HUE

The hue can be matched by taking the correct proportions of two of the three subtractive primary (complementary) colours. The function of the third complementary when combined in a quantity less than that of the other two is to form the required amount of black which darkens or degrades the colour, and lowers the luminosity.

Suppose for example a perfect match of the colour is obtained with 2 units of cyan, 4 of magenta and 6 of yellow. The 2 units of cyan together with 2 units of each of the other two will form black, and the ratio of the remaining 4 units of yellow and 2 units of magenta are the amounts of the two complementaries actually used in producing the hue, or in other words the colour itself.

SATURATION

The saturation of the colour is dependent on the amount of pigment used in forming the hue. As this amount is reduced, the filtering action of the pigment becomes less and more white light will be allowed to pass. The saturation is therefore reduced and the colour appears less vivid.

Translating theory into practice, we can now see that the effect of increasing the exposures of all three bromide prints will be to add an equal quantity of the three subtractive primaries.

As these will form black and the colours will be darkened, this does not alter their hue or saturation, but may make them appear darker than in the original subject. The effect is analogous to altering the tone rendering in a monochrome print by printing it darker and is to a certain extent a matter of taste.

The result of lowering the contrast of the print is to decrease the amount of the two primaries used in matching the hue. The colour will become less saturated and the equivalent tone contrast of the print is of course reduced in the same way as with monochrome work.

Although we have so far considered colour reproduction from the point of view of the subtractive primary colours, it is easier for many purposes and more logical, to think of the function of a subtractive primary as being that of absorbing the complementary additive primary, e.g., cyan absorbs red. In the case of a colour print the method of doing this is as follows :

Let us assume that the white light falling on the print is composed of 100 units of red, 100 of green and 100 of blue. The colour which we wish to reproduce can be matched by using cyan magenta and yellow pigments of densities 0.6, 0.9, and 1.3 respectively. The corresponding

transmissions (reciprocities of opacities) are then $\frac{1}{4}$, $\frac{1}{8}$, $\frac{1}{20}$. We then have :

MATCHING HUES

	Red	*Green*	*Blue*	
Incident Light	100	100	100	units
After passing through cyan	25	100	100	units
After passing through magenta	25	$12\frac{1}{2}$	100	units
After passing through yellow	25	$12\frac{1}{2}$	5	units

The hue is therefore matched by $25 - 5 = 20$ units of red and $12\frac{1}{2} - 5 = 7\frac{1}{2}$ units of green. The remaining 5 units of each primary form white, which desaturates the colour.

CONTRAST AND HUE

It may come as a surprise to many workers to know that altering the contrast also affects the hue. Unless the contrast of the finished print approximates to that of the original subject, the colours will be altered to an extent depending on the proportion of the primaries used in matching their hue.

This may be illustrated by considering some part of a print in which the densities of the cyan, magenta and yellow are say 0.3, 0.6 and 1.0. The transmissions on reflectances of the additive primaries red, green and blue, are then proportional to :

$$\frac{1}{\textit{cyan opacity}} = 0.5 \textit{ of red.}$$

$$\frac{1}{\textit{magenta opacity}} = 0.25 \textit{ of green.}$$

$$\frac{1}{\textit{yellow opacity}} = 0.1 \textit{ of blue.}$$

Subtracting the 0.1 of white light (formed with the blue) we have a ratio of red to green equal to :

$$\frac{0.5 - 0.1}{0.25 - 0.1} = 2.67.$$

Now supposing that the contrast of the bromide prints (or separation negatives) is reduced by 25 per cent say from $\gamma = 1$ to $\gamma = 0.75$. The corresponding densities of the three subtractive pigment images are also reduced by 25 per cent and become 0.225, 0.45 and 0.75. The transmissions or reflectances are then red = 0.60, green = 0.35, and blue = 0.18.

So the ratio between the red and green is $\frac{0.60 - 0.18}{0.35 - 0.18}$, or 2.47.

In other words, the hue is less red and more green, i.e., a more yellowish hue than before.

By working out this calculation for different colour ratios and changes of contrast the following may be deduced :

(*a*) As the contrast is varied, all colours except those formed by one additive primary or equal mixtures of these primaries, will alter. This variation will be most pronounced when the ratio between the amounts of the primaries forming the hue is large. The colours which remain unaltered are therefore the three additive and the three subtractive primaries and of course grey.

(*b*) As the contrast is decreased, the dominant additive primary forming the hue becomes progressively less dominant : a red orange will become more yellowish. If the contrast is increased, the reverse effect occurs.

In practice the alterations in hue which occur due to varying the contrast within reasonable limits are not very noticeable and are masked by the change of saturation. However the aim should always be to produce a print in which the grey scale is of equal or slightly greater contrast than that of the original.

LIGHTING CONTRAST

In colour work the maximum lighting contrast which can safely be used on any subject is governed by three factors :

(*a*) The density or luminosity contrast of the colours. This is equivalent to the black and white contrast which is met with in monochrome subjects, even if perfectly flatly lit, e.g., a chess board.

(*b*) The hue of the colours. If the colour is almost entirely composed of one of the primaries, the other two will only just record and a large part of the available photographic range will be taken up in defining the colour.

(*c*) The saturation. Although the ratio between the amounts of the primaries forming the hue remain the same whatever the degree of saturation, a highly saturated colour will require a greater pigment density in order to decrease the proportion of white light transmitted. The density range required to record the colour will therefore increase with the saturation.

The last two points can be illustrated if a bowl of grapefruit is chosen for the subject and the process considered at the bromide print stage. The silver density on the bromides necessary to reproduce the yellow of the fruit with correct saturation and luminosity may be cyan printer = 0.1, magenta printer = 0.4, yellow printer = 1.0.

If the maximum and minimum densities of the bromide which the process can handle are 0.1 and 1.4, there is an available density range of 1.3. Of this 0.9 will be required to record the colour. Now suppose that the amount of light falling on one of the grapefruit is only $\frac{1}{3}$ of that on the others, the density range required (assuming an overall

gamma of unity) is 0.9 + log 3 = 1.38 approx. which is more than the process can give.

If the colour had not been as saturated as was assumed in the above example, the same difficulties would not arise. With decreased saturation the hue could be matched with cyan printer density 0.1, magenta 0.36, yellow 0.77. The available density range is then 1.3 − 0.65 = 0.65, and a 4 : 1 lighting contrast range would be permissible.

In this example it must be remembered that densities are logarithmic and in order to compare the ratio between the yellow and magenta the densities must first be converted to transmissions (p. 131).

In practice all we need to remember is that the permissible lighting contrast range will increase as :

(*a*) The amounts of the primaries required to match the colours of the subject become more nearly equal, i.e., the greyer the colours are.

(*b*) The colours in the subject become more equal in luminosity, i.e., all colours are either light or dark.

Similar consideration also apply to transparencies, and to separation negatives, and it is worth remembering that masking (p. 135) compensates for some of the imperfections of the dyes and makes it possible to obtain the same colour saturation with a lower contrast thus increasing the effective range of the process.

MASKING DIRECT SEPARATION NEGATIVES

Very good colour prints can be made from separation negatives taken direct from the subject by the methods described so far, yet highest quality colour reproduction requires *masking*.

The essential point about masking is absolutely accurate work. The improvement gained is not very great, though it is distinctly noticeable. Any working methods falling short of the high standard of accuracy necessary will only produce results that are worse than those obtainable without masking.

In its essentials masking consists of making from a negative a low contrast positive and binding it in register with the negative during enlarging. The positive has a maximum density where the negative is lightest, and vice versa, so that the effect of the mask is to lower the contrast of the combination and in the extreme case to convert it into a positive.

The change of contrast is dependent on the gamma of the positive and not on its actual density as an increase in the latter is really only equivalent to interposing a neutral filter between the negative and the light source.

THE PURPOSE OF MASKING

In colour work the chief application of masking is for correcting faulty colour rendering due to the imperfections of the colour dyes.

In a theoretically ideal set of dyes for the subtractive process each pigment should perfectly reflect its own colour and completely absorb the complementary, e.g., cyan will

reflect blue and green and absorb red. Unfortunately, although yellow pigments are usually satisfactory, the available cyan and magenta dyes depart very far from the theoretical ideal.

The chief defects of these dyes, which may be seen by looking at them through tricolour filters, are :

(*a*) The cyan dye absorbs not only red but some green and to a lesser extent blue.

(*b*) The magenta which should absorb only green, also absorbs some blue.

This latter point is the proper function of the yellow dye, and the magenta may therefore be considered as having an unwanted addition of yellow. Correspondingly the cyan has unwanted magenta which again should properly be the function of the magenta dye.

These defects tend to produce falsification in the rendering of the following colours :

Blues and greens become darker and greyer.
Blue-greens lose their greenish hue.
Mauves become brownish.
Reds lose any bluish tint they may possess.

If a positive mask is made from the cyan printer negative and bound up with the magenta printer, the magenta content, and thus the magenta balance, in the final print can be reduced by an amount approximating to the unwanted inclusion in the cyan dye.

Similarly by adding a mask made from the magenta printer negative and adding it to the yellow printer, the unwanted yellow is reduced.

For theoretically perfect colour correction at least two masks would be required to each negative, but from a practical point of view the difficulty of accurately controlling the contrast of each mask would make such a procedure hardly worth while.

MASKING SYSTEMS

For correcting the imperfections in colour rendering due to the pigment dyes, only two masks are essential ; but as these would have the effect of upsetting the contrast balance of the separation negatives and most systems employ a minimum of three masks. The following is a good method :

1. Make a positive from the green filter negative and bind in register with the blue filter negative.

2. Make a positive from the red filter negative and bind in register with the green filter negative.

3. Make a positive from the red filter negative and bind in register with the red filter negative. This mask has no effect on colour rendering but equalises contrast with the other negatives.

The density range of the masks should be about 30 per cent of that of the separation negatives, which is equivalent to saying that the masks should be developed to a gamma of 0.3. The density of the masks is not critical, but the aim should be for the minimum density to be just above the fog level of the sensitive material, a density between 0.15 and 0.25 is about right.

The best type of plate to use is one which does not produce excessive contrast, and which will give a good straight-line characteristic curve when developed to a low gamma.

EXPOSING AND DEVELOPING THE MASKS

Probably the easiest way of exposing the mask is to use an enlarger as the printing light source.

It should be raised to its maximum height and a sheet of ground glass put immediately underneath the lens. Besides reducing the amount of light reaching the negative, the ground glass has the advantage of ensuring that the

illumination is even. Initially the exposures will have to be found by trial and error, but as a very rough guide it is worth remembering that a medium speed (23 Scheiner) film or plate is about 50 times as fast as bromide paper.

In order to obtain the low gamma required without making the development time too critical a soft working developer must be used. The formula given on p. 29 for the plain metol developer is suitable with the addition of 8 drops of 10 per cent potassium bromide per ounce (0.5 c.cm per 30 c.cm.) of stock solution.

If the stock solution is diluted 1 part to 5 parts of water, the development time to produce a gamma of 0.3 is about 4 minutes with a plate like Ilford *S.R. Pan.* An alternative is to use a developer like *ID 48* or *DK 20* and to dilute it with an equal quantity of water. The time of development will then be about 4½ minutes. It will be found that with these times an increase of as little as ¾ minute may raise the gamma from 0.3 to 0.4 so that careful control of time and temperature is important.

INITIAL TESTS

Before the worker attempts to make his first set of masks he should carry out tests to find out the development time necessary to produce a gamma of about 0.3 in the mask and also to establish an exposure constant for the particular source of illumination which is to be used. It is here that a densitometer becomes so desirable, as otherwise it is difficult to judge whether the mask has been developed to the right contrast.

The easiest way of carrying out the tests is to use a step wedge. The Enlarging Negative from the *Focal Enlarging Chart* can be used for this purpose.

Expose the plate under this for a time which it is estimated will be about right when making a mask from a

normal separation negative. Develop the plate. When dry measure the densities of each of the steps on the plate and the corresponding densities of the step wedge. From these results the characteristic curve can be plotted (p. 109), and the gamma measured, or alternatively calculated :

$$Gamma = \frac{\textit{Difference in density between any two steps on the negative}}{\textit{Difference in density between corresponding steps on the wedge}}$$

If necessary the test should be repeated varying time of development until the required gamma is obtained.

In a good set of separation negatives the maximum density is usually between 1.0 and 1.4. The exposure of the masks must therefore be such as to give a corresponding minimum density of 0.15 to 0.25

It is convenient to calculate the standard mask exposure on a maximum density of 1.0 ; then by measuring the greatest density in any set of separation negatives the correct mask exposure can be calculated with a minimum of arithmetic. In order to find this standard exposure, measure the density of one of the lighter steps in the test negative and that of the corresponding step of the wedge. The standard mask exposure for a maximum negative density of 1.0 is then given by :

$$\textit{Standard Exposure} = \textit{Exposure of Test Negative} \times \frac{O_1}{O_2} \times \textit{opacity of} \frac{D_3 - D_4}{\gamma \textit{ of test neg.}}$$

where O_1 = *Opacity of standard negative* (= 10)

O_2 = *Opacity of step wedge*

D_3 = *Minimum mask density*

D_4 = *Density of corresponding step in test negative*

When D_4 is greater than D_3, this becomes

$$\textit{Standard Exposure} = \textit{Exposure of Test Negative} \times \frac{O_1}{O_2} \times \frac{1}{\textit{opacity of } (D_4 - D_3)\,/\gamma}$$

The mask exposures for any set of separation negatives are then obtained by multiplying the standard exposure by *Maximum opacity in the negatives*/10.

If the worker does possess a densitometer he will have to decide on the correct time of development by estimating when the test negative has a density difference between its steps equal to about $\frac{1}{3}$ of that of the wedge from which it was made.

The exposure can also be estimated by noting the stey in the wedge which gives a density just above fog level and regarding this as the standard with which to compare the maximum density which occurs in a set of separation negatives.

BINDING THE MASK IN REGISTER

Probably the easiest way of registering the mask is to place the negative on a sheet of paper and to illuminate it from behind. If the mask will not register, it may be due to one of the causes mentioned on p. 90.

The normal method of binding the mask in register is to use gummed paper, but a very satisfactory alternative is to put a small drop of a cellulose cement, e.g., *Durofix* at each corner. This takes about 5 minutes before it starts setting. The fluid is just sufficiently viscous to prevent the negatives sliding easily over one another when registering and this is distinctly helpful. After three or four hours the negatives will be firmly fixed together, but it is usually possible to separate them by inserting a razor blade at the corners.

MASKING NEGATIVES NOT BALANCED FOR CONTRAST

If the separation negatives are out of balance in their contrast, the position is very much complicated. From the colour correction point of view each mask should be developed to give a fixed contrast ratio relative to the negative with which it is to be registered.

For example, the grey scale density range may be :

Red filter negative : 1.20
Green filter negative : 1.20
Blue filter negative : 1.50

If 33 per cent masking is being used, the mask made from the green filter negative should have $\frac{1}{3}$ of the density range of the negative with which it is to be registered, e.g., the blue filter. This gives $\frac{1.50}{3}$ or 0.5 and to produce this it must be developed to a gamma of $\frac{0.5}{1.20} = .41$. Similarly the other two masks should have a density range of $\frac{1}{3}$ of $1.20 = 0.4$ and a corresponding gamma of $\frac{0.4}{1.20} = 0.33$.

It is unlikely that the average worker would succeed in making masks to these specifications. Even if this were done, the masked negatives still present the problem of unbalanced contrast when it comes to making the colour print.

The difficulty should of course never occur if the development times of the separation negatives have been adjusted so as to produce balanced contrast. If it does arise the best solution is approximately to balance the negatives by intensification (p. 24), or to reduce the contrast of the offending negative by making a mask and binding it up in register. This will mean that one of the negatives will ultimately have two masks. The first of these should be made on thin film which can then be sandwiched between the negative and the outer mask.

UNSHARP MASKS

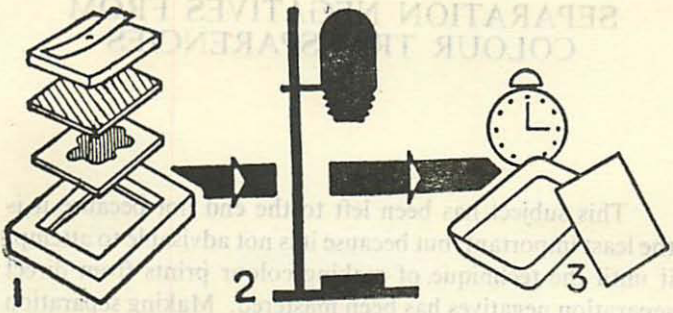
An unsharp mask, is one where the image is not sharp as in a contact print, but somewhat diffused.

The advantages of using an unsharp mask are that registration is not quite so critical and that it also *increases* resolution. The reason for this is that whereas the mask reduces contrast in the coarser details of the subject, it does not resolve fine detail but merely overlays it with a uniform density which has no effect on contrast. Consequently if during the printing process the contrast is increased to bring it back to that of the unmasked negative, the fine detail benefits and resolution is increased.

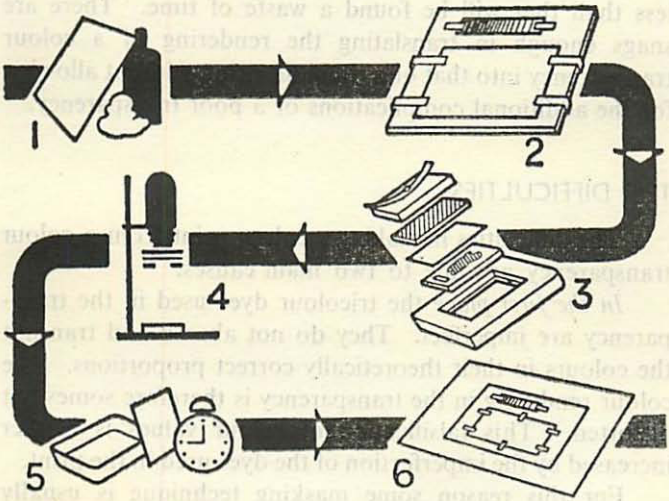
INTRODUCING THE DIFFUSION.—Diffusion may be obtained by putting a transparent spacer about .01 in. (0.25 mm.) thick between the negative and mask and printing from a broad light source.

In the first method the degree of diffusion produced will depend on the thickness of the spacer and the width and on the distance of the light source. With a 0.01 in. spacer a 6 × 6 in. diffused light source at 3 ft. distance should give satisfactory results for quarter-plate, but for smaller sizes the size of the light source should be reduced to about 2 × 2 in.

THE SIZE OF THE MASK.—When using a broad light source (say about 6 in. or 15 cm. square), the subject detail in the mask is larger than that of the negative. When the masked negative is enlarged, the mask will be nearest to the enlarger lens and as it is then in a convergent beam of light, the mask detail ought to be smaller than that of the negative. In practice this does not seem to be of great importance except when working with small negatives. The difficulty does not arise to the same extent with colour transparencies or film negatives as the mask can be made through the celluloid base and will then be on the side of the negative next to the enlarger light source.



Steps in making a mask (p. 137). 1 Place negative and positive material in printing frame. 2 Expose under enlarger light. 3 Develop to low gamma.



Steps in making Kodachrome transparency mask (p. 147). 1 Clean transparency. 2 Mount on glass with grey scale. 3 Place in printing frame with spacer and negative material. 4 Expose through filter under enlarger light (diffused with ground glass ; fixed size of light source). 5 Develop. 6 Bind in register with transparency.

SEPARATION NEGATIVES FROM COLOUR TRANSPARENCIES

This subject has been left to the end not because it is the least important, but because it is not advisable to attempt it until the technique of making colour prints from direct separation negatives has been mastered. Making separation negatives from colour transparencies requires accurate work and careful tests even more so than for direct separation work.

The prime requirement for successful prints from colour transparencies is a perfect transparency. Anything less than that will be found a waste of time. There are snags enough in translating the rendering of a colour transparency into that of a tricolour print, without allowing for the additional complications or a poor transparency.

THE DIFFICULTIES

The difficulties in making a colour print from a colour transparency are due to two main causes.

In the first place the tricolour dyes used in the transparency are imperfect. They do not absorb and transmit the colours in their theoretically correct proportions. The colour rendering in the transparency is therefore somewhat distorted. This falsification of colour values is further increased by the imperfection of the dyes used in the print.

For this reason some masking technique is usually considered essential if good colour rendering is to be obtained. This involves quite a bit of extra work.

It is, however, possible to produce passable results without masking, particularly if the subject is of low con-

trast and only one or two colours have to be accurately rendered.

The second difficulty arises because a transparency which is viewed by transmitted light can accurately record a greater subject contrast range than a print which is limited by the difference in the amount of light which can be reflected from the lightest and darkest parts on the paper.

The ideal transparency from which to make a colour print is therefore one with a relatively low subject contrast. Preferably it should be made slightly darker than would be considered ideal for projection, by under-exposing it by about half a stop.

Although it is possible to correct faulty colour balance in a transparency during subsequent printing operations this makes the process much more difficult.

Where practice it is well worth while including a grey scale in the subject as this makes it much easier to correct any errors in colour rendering which may have occurred.

MAKING THE SEPARATION NEGATIVES

When making separation negatives from transparencies the normal tricolour filters are not suitable. Instead special narrow cut filters must be used. To obtain best results these should be specifically designed to suit the particular make of transparency in use. This is because the filters ought to accept only the bands of light transmitted by the dyes used in the transparency.

Sets of such narrow-cut filters are the Ilford 205 (red), 408 (green), and 306 (blue), and the Wratten F (red), N (green), and C4 (blue). Dufay also issue a special set of filters for use with Dufaycolor transparencies.

The separation negatives may be obtained by one of the following methods :—

(*a*) Illuminating the transparency from behind and

copying with a camera. The tricolour filters are placed either in front of the light source, or on the camera lens in the same way as when making direct separation negatives.

(*b*) Filtering the light source and making the separation negatives by contact printing from the transparency.

(*c*) Enlarging the transparencies in an enlarger on to the negative material on the baseboard. The filters are fitted over the enlarging lens.

For the amateur the last two of these are probably the best since they require no special apparatus. Contact printing is very easy for quarter-plate or larger sizes, but is impracticable for use with transparency masks in the smaller sizes. This is due to the difficulty of obtaining good registration between the mask and transparency without sandwiching them between glass.

MASKING TO REDUCE CONTRAST

Most transparencies are developed to high contrast and may have a difference in density of nearly 3.0 between the lightest and darkest parts. This represents a 1,000 to 1 opacity range which may be further increased as between the three separation negatives. For this reason it is nearly always necessary to use a contrast reducing mask on the transparency so as to bring its range within that of the negative material used for making the separations. This is particularly important where the separations are made with an enlarger, as the light scatter which occurs in the lens is accentuated with high contrasts and degrades the image.

Colour correction can either be obtained by masking the transparency itself or by masking the separation negatives afterwards. The procedure then being similar to that already described for masking direct separation negatives.

The transparency mask system has the advantage that

the contrast reducing and colour correcting masks can be combined. Also the filters used for making the masks can be specifically made to suit the type of transparency in use. On the other hand it cannot be used successfully if the contrast balance of the transparency has been upset. This often happens when a transparency is under-exposed. The effect is similar to that obtained in a colour print when the separation negatives are of unequal contrast, e.g., the colour rendering may be correct in the lighter portions of the transparency but the colour of the darker parts is falsified.

If the transparency mask system is used the error will be accentuated. This difficulty can be overcome by using a plain contrast reducing mask on the transparency when making the separation negatives and then harmonising the contrast with the chromium intensifier mentioned on p. 24 before masking them.

Kodak Ltd. have developed and patented transparency one-mask and two-mask systems for use with *Kodachrome* and *Ektachrome* transparencies. These are very fully described in leaflets which are obtainable from Kodak Ltd. The general working procedure is detailed below.

KODAK TRANSPARENCY MASK FOR KODACHROME

The procedure for making the unsharp contrast and colour correcting mask for Kodachrome transparencies is as follows :

1. Clean both sides of the transparency by polishing with a soft cloth. If necessary cine cleaning fluid or carbon tetrachloride can be used for removing obstinate markings.

2. Mount the transparency *emulsion side* down on the glass of a printing frame using thin adhesive tape and add a neutral density wedge with a density range of 0 to 3 at one side for reference. In the case of 35 mm. transparencies it is advisable to block out the unwanted portion of the

glass support and to make four crosses at the corners. These will then record on the mask and assist in subsequent registration. Special marginal mask plates with the step wedge and registration marks incorporated can be bought for this purpose.

3. The mask should be made on a pan plate which has a long straight-line portion of its characteristic curve such as the high-speed types. A clean sheet of 0.005-in. celluloid is mounted over the transparency, this together with the thickness of the transparency base separates the image from the plate and produces the required unsharpness in the mask.

4. The exposure is made to light filtered through a Wratten tricolour red filter No. 25 (A) and adjusted to give a minimum density on the mask of between 0.15 and .2. The plate is then developed in a soft working developer, e.g., metol (see p. 29) to a gamma of about 0.3, which gives the mask 30 per cent of the transparency density range.

5. After processing the mask is bound up in register on the back of the transparency, omitting the celluloid spacer. For smaller sizes, the transparency should be left on its glass support and will therefore be sandwiched between it and the mask. This precludes the possibility of obtaining the separation negatives by contact.

6. Registration can best be carried out by laying the mask face upwards in a horizontal position and illuminating it from behind. As the two images will be separated from each other by the thickness of the transparency base, a parallax will occur unless the image is viewed from vertically above. A magnifying glass is a great help in this.

TRANSPARENCY MASKS FOR EKTACHROME

For maximum colour correction with Kodachrome and for all Ektachrome transparencies a two-mask system is

recommended. The procedure is similar to that described above, but two masks are made one through a Wratten No. 72A red filter, and one through a Wratten No. 58 (B2) pale green filter. The red filter mask is bound in register with the transparency when making the red and green separation negatives and is replaced by the green filter mask while the blue filter negative is made.

TRANSPARENCY CONTRAST REDUCING MASKS

Any subject taken in colour has :

(*a*) A black and white contrast. This is chiefly a function of the subject lighting contrast ; and

(*b*) A colour contrast, which is inherent in the subject and must not be altered if the saturation or " vividness " of the colours is to be reproduced.

If a mask is made from the transparency by unfiltered (white) light and bound up in contact, its approximate effect will be to reduce the lighting contrast of the subject without altering the colour contrast. This effect can easily be demonstrated by making a white light mask developed to a gamma of 1.0 and binding it up with the transparency —only the colour contrast remains !

The Kodak transparency system combines the functions of colour correction and contrast reduction. However, with this method the two functions cannot be separated, and it is sometimes useful to be able to do this, especially when lighting contrast of the subject was too great.

The procedure is as follows :

1. Make a white light mask and bind up in register with the transparency. The gamma of this mask can be varied between about 0.2 and 0.4, depending on the reduction in black and white contrast required.

2. Make separations from the transparency in the normal way. A gamma of 0.7 to 1.0 is required to allow for the subsequent masking.

3. Mask the separation negatives. The masks should have a gamma between 0.25 and 0.4.

In the case of direct separation negatives a similar result could be obtained by using two masks on each negative, one for colour correction and one for reducing the black and white contrast. The latter masks would have to be made from a grey printer negative, i.e., an unfiltered negative of the subject.

TRANSPARENCY HIGHLIGHT MASKS

Owing to the pronounced toe which is found in the reproduction curve of most colour transparency materials, the contrast and colour saturation of the lighter parts of the transparency tend to be too low. This trouble may be accentuated in the colour print.

The difficulty can be largely overcome by using a highlight mask. The mask is made from the transparency, on a contrasty panchromatic plate and exposed to white light with the plate separated from the emulsion side of the transparency by a spacer in order to introduce unsharpness (p. 142). The exposure and contrast must be adjusted so that the mask has a maximum density of 1.5 to 2.0 for the lightest part of the transparency while no density is recorded for the middle and shadow tones.

The mask is then bound in register with the emulsion side of the transparency while the normal colour correcting masks (p. 147) are made, and is then discarded.

With the highlight mask in register the lightest parts of the transparency should be almost as dense as the shadows, but the appearance of the middle and darker tones should be unchanged.

MAKING THE SEPARATION NEGATIVES BY CONTACT

Whether the separation negatives are made by contact or projection, the aim should be to produce a set of negatives in which the minimum density is between 0.3 and 0.4 and have a density range of about 0.8 to 1.0. This means that the negatives should be developed to a gamma of roughly 0.65. It is not necessary to adjust the development for each set of negatives and only the exposure times require altering in order to obtain the correct minimum density.

If the negatives are made by contact, the filters must be placed in front of the light source. The area of each filter should be so adjusted that the exposures for the separation negatives are approximately equal.

The filters can be surrounded by opaque masks and then fitted in in place of the normal screen of a safelight. Alternatively the masks can be put into the carrier of an enlarger and a sheet of ground glass fitted below or in place of the lens, so as to spread the light and give a source of illumination of about 3–4 sq. in. If this latter method is adopted, it may be necessary to use a photoflood bulb in the enlarger, in order to get sufficient illumination.

It is difficult to give any reliable guide as to filter factors or exposures, as these will depend on type of plate, colour temperature of the light source, the filters in use, the density of the transparency, and the relative development times. An average set of filter factors is red = 8, green = 12, blue = 25. But the only satisfactory method is to carry out tests with a step wedge in a similar manner to that recommended on p. 120.

The tables (p. 152) give a guide for exposure and development times for transparency masks and separation negatives recommended by Kodak when using the P.1200 plate. The filters are mounted in front of a safelight lamp with 60 watt bulb. The distance from the filters to the printing frame is 3 ft.

SEPARATION NEGATIVES FROM KODACHROME

Negative	*Wratten Filter*	*Filter Aperture*	*Approx. Exposure*	*Developer and dilution*	*Dev. Times 65°F. (18° C.) Dish*	*Tank*
Transparency Mask	25 (A)	$1\frac{3}{4} \times 1\frac{3}{4}$ in.	35 sec.	D6Ia, 1 : 1	$3\frac{1}{2}$ min.	—
Red filter	29 (F)	$1\frac{3}{8} \times 1\frac{3}{8}$ in.	60 sec.	D6Ia, 1 : 1	$3\frac{3}{4}$ min.	4 min.
Green filter	61 (N)	2 × 2 in.	60 sec.	D6Ia, 1 : 1	$3\frac{3}{4}$ min.	4 min.
Blue filter	49 (C4)	4 × 4 in.	60 sec.	D6Ia, 1 : 1	$4\frac{3}{4}$ min.	5 min.

SEPARATION NEGATIVES FROM EKTACHROME

Negative	*Wratten Filter*	*Filter Aperture*	*Approx. Exposure*	*Developer and dilution*	*Dev. Times 65°F. (18° C.) Dish*	*Tank*
Transparency Masks	72A	$1\frac{3}{4} \times 1\frac{3}{4}$ in.	40 sec.	D6Ia, 1 : 1	$3\frac{1}{2}$ min.	—
	58	$1\frac{3}{4} \times 1\frac{3}{4}$ in.	40 sec.	D6Ia, 1 : 1	$3\frac{1}{2}$ min.	—
Red filter	72A	$2\frac{1}{2} \times 2\frac{1}{2}$ in.	90 sec.	D6Ia, 1 : 1	$3\frac{3}{4}$ min.	4 min.
Green filter	58 (B2)	$1\frac{3}{4} \times 1\frac{3}{4}$ in.	90 sec.	D6Ia, 1 : 1	$3\frac{3}{4}$ min.	4 min.
Blue filter	47 (C5) + 2A	$3\frac{1}{2} \times 3\frac{1}{2}$ in.	90 sec.	D6Ia, 1 : 1	$4\frac{3}{4}$ min.	5 min.

MAKING SEPARATION NEGATIVES BY PROJECTION

This method is used for smaller transparencies.

In order to avoid buckling, the transparency should be left on the glass or marginal mask plate to which it was fixed when making the mask. The mask is then registered with a magnifying glass by moving the two plates relative to each other. They are then held in position with bulldog clips while each side in turn is bound together with tape.

The mask and transparency are then put into the negative carrier which must be made light tight. The filters can be mounted in cardboard mounts close to the lens.

With the filter in position, the enlarger is focused and the separation negatives exposed.

If the transparency is a heavy one, a clear gelatine filter can be used while focusing. The lens aperture must not be

varied to control the exposure between the three separation negatives, because this may change the image size.

Not all enlarger lenses are properly corrected for chromatic aberration and will not therefore bring the three filter images to the same point of focus. If there is any doubt it is worth testing the lens before starting work.

One method is to make two enlarged negatives through the red and blue filter respectively. A positive transparency is made from one of these negatives, and when dry, registered with the other. If registration is perfect, the lens may be considered as satisfactory.

INITIAL TESTS

The only reliable way of finding the correct exposure and development times for the masks and separation negatives is to make initial tests.

Where only one mask is used, the procedure is similar to that already described for masking direct separation negatives (p. 138). In the case of the separation negatives and the two filter mask system, the times of development required to produce the same contrast in each of the negatives will almost certainly be different.

A suggested procedure is as follows :

1. Using a step wedge, expose a separate plate under it to light filtered through each of the separation or mask filters in turn. The exposures (or area of the filter apertures) should be proportional to the estimated filter factors and sufficient to record most of the steps of the wedge.

2. Develop the negatives for times estimated to produce the desired contrast in each negative.

3. Now measure the density difference between one of the medium density and one of the darker steps in each of the negatives. The gamma will be given by :

$$\gamma = \frac{\textit{Density difference between steps of negative}}{\textit{Density difference between corresponding steps of wedge}}$$

The extent to which the filter factors require correction can be found by comparing the relative opacities of any corresponding step in each of the negatives.

As the actual exposures given at this stage are not of great importance, one of the filter negative exposures can be taken as standard and the others altered to conform with it. If the red filter negative is chosen, the other filter factors must each be divided by :

$$\textit{Opacity of} \frac{\textit{Density difference between red filter negative and other negative}}{\textit{gamma}}$$

If the contrast of the negatives is unequal, the development times will have to be altered.

When the correct development times have been found and the relative exposures adjusted to suit the filter factors, the standard exposure for contact printing can be calculated. This should be based on a maximum transparency density of 3.0 producing a density of 0.3 in a separation negative, or about 0.2 in a mask.

It may be calculated from the formula :

$$\textit{Standard Exposure} = E \times \frac{O_1}{O_2} \times \textit{opacity of} \frac{D_3 - D_4}{\gamma}$$

where

E = *Exposure of test negative*

O_1 = *Standard maximum opacity of transparency* = 1,000

O_2 = *Opacity of step wedge*

D_3 = *Minimum density required in negative or mask*

D_4 = *Density of step in negative corresponding to that measured in the step wedge*

γ = *Gamma to which the negatives were developed*

When D_4 is larger than D_3, the equation becomes :

$$\textit{Standard Exposure} = E \times \frac{O_1}{O_2} \times \frac{1}{\textit{opacity of } (D_4 - D_3)\,/\gamma}$$

The adjustments required to the standard exposure to suit any particular transparency can easily be found from the formula below if the maximum opacity of the transparency is measured :

$$\textit{Exposure} = \frac{\textit{Standard exposure} \times \textit{maximum opacity of transparency}}{1000}$$

It must be emphasised that although for those photographers who possess a densitometer, some method based on densitometry will waste least time and material, it is still perfectly possible to obtain the desired results by trial and error.

THE USE OF A GREY PRINTER

One of the criterions by which pigments or dyes are selected for a colour printing process is that when mixed in suitable proportions they should be capable of producing a good grey scale which extends from light grey to black. With most printing inks this condition is only partially met ; although it may be possible to obtain a light grey, it does not follow that when the inks are printed more heavily in the same proportions a black will result. For this reason most ink printing processes use a fourth printing of black ink to give " body " to the picture.

Fortunately the Carbro pigments are capable of producing good blacks, and a grey printer is quite unnecessary and in fact undesirable, except for special work. Its chief applications are :

(*a*) In cases where it is vital to maintain an even grey over a large or intricate part of a picture.

(*b*) In minimising the effect of colour wander in a difficult background.

(*c*) In making alterations to the density of different parts of the picture without danger of altering the colours.

The effect of making a grey printing and adding it to the colour print is to darken or degrade all the colours, and make the print denser. This is often unacceptable, and the choice then lies between :—

(*a*) Local control on the grey printer when printing ; developing it to a high contrast so that it only records in the shadows ; or by bleaching out unwanted portions.

(*b*) Using some masking technique on the negatives so that the grey printer forms an integral part of the colour reproduction process. This method depends on the fact that in a three-colour printing process a colour is always matched in hue by only two of the printing dyes, the third dye in conjunction with equal amounts of the other two forming the required amount of grey. (See p. 129.)

THE BROMIDE PRINT AS GREY PRINTER

Assuming for the moment that a grey printer bromide has been made, we can either make a carbro image from it using a sheet of black monochrome carbro tissue and transfer it to the soluble temporary support after putting down the colour images. Alternatively, we can use the bromide print itself as the base on which to transfer the colour images as in single transfer. (P. 77.)

This is the easiest way, but it has certain snags. In the first place the image on the grey printer bromide must be reversed in relation to the colour printing bromides, otherwise single transfer is not possible. This means that either the grey printer negative must be made with the image reversed, or it must be turned round in the enlarger, in which case it needs careful adjustment to make the image size correspond with the colour printing bromides.

The same type of paper should be used for all four bromides, so that they will expand equally and in the same direction when wetted.

Since the bromide surface is not suited to picking up the colour images direct from the transparent supports, some gelatin solution should be used as a cement when registering the yellow image. A 10 per cent solution of gelatin is suitable, it can be made by soaking Nelson's No. 1 Gelatin in cold water to allow it to expand and then heating until it dissolves. The solution will set into a jelly when cold, and must be warmed each time it is used.

The order in which the colour images are transferred to the base is yellow, magenta, cyan. Registration of the yellow on the grey printer, and the magenta on yellow, is visually not easy and it may be necessary to view the images through a blue filter.

There are a number of other possibilities when using the grey printer bromide as the final transfer. For instance, where a coloured object is wanted against a plain black and white background, the reliefs can be combined on the S.T.S., trimmed with scissors, and then transferred to the bromide as the final support. The difficulty with this method is to allow for the expansion of the S.T.S. when wet. The bromide must be hardened in an acid hardening bath in order to stand up to the hot water during final development. It is doubtful whether the final combination of a carbro image surrounded by a plain bromide image is suitable except for commercial work.

A great deal of control is possible by bleaching out unwanted portions of the image either on the three colour printing bromides, on the grey printer, or a combination of both. It is even possible to do this after the print has been assembled, but it may take some time for the bleacher to diffuse through the carbro image and it is difficult to confine its action to the right parts.

Where bleaching has been done on the finished print, it should be thoroughly washed in several changes of water, but must not be fixed in hypo, as this reduces the yellow pigment image. A strong solution of plain ferricyanide is recommended for the bleacher, as it has no effect on the colour images.

OBTAINING THE GREY PRINTER NEGATIVE

The easiest way of obtaining a grey printer negative for direct separation negatives is to make a fourth exposure through one of the yellow green filters normally sold for the

purpose. The only other satisfactory method is to make a low contrast positive from each of the separation negatives, bind these in register, and then make a grey printer negative from the combination—rather a lengthy procedure.

In the case of a transparency, it is only necessary to make a fourth separation negative using unfiltered light.

Since by these methods the grey printer is really a hindrance to correct tone reproduction in the colour print, its density and contrast can only be found by experiment.

The alternative method of using the grey printer is to make it take a part in the colour reproduction. If we make a white light mask from a transparency to a gamma of 1 and then bind it up in register, the adjacent parts of the picture are only differentiated by the variations in the hue and saturation of the colours. In other words the black and white contrast has been removed. (See also p. 149.) This can be restored in the colour print by a grey printer made from the white light mask.

It is inadvisable to go quite as far as this, and for a first trial procede as follows :—

1. Make a white light mask to a gamma of, say, 0.6 by exposing through the back of the transparency to a small light source.
2. Make separation negatives from the transparency with the white light mask in position, and develop to a gamma of about 1.
3. Mask these negatives for colour correction, treating in exactly the same way as when masking direct separation negatives (see p. 137).
4. Make the bromide prints in the normal way.
5. Make the grey printer bromide from the white light mask, using a softer grade of paper than is used for the colour printing bromides.

CONTRAST AND DENSITY

It is difficult to decide on the contrast and density to which the colour printing bromides and the grey printer

should be made. Obviously little or no grey is needed in the lightest parts of the print, and this gives a fair indication as to the density needed in the grey printer. Its contrast will depend on the gamma of the mask which has been used to remove the grey, and on the contrast of the pigment images in relation to the parent bromides.

The simplest answer is to work by trial and error and to make two or three grey printer bromides of different contrast and to select the best of these at the trial registration stage. The tendency when working from transparencies is to find that the contrast of a grey printer made from the mask is too great, and it may be worth while making an additional white light negative from the transparency developed to a low gamma to use as the grey printer negative.

The effect of varying the contrast of the grey printer is simply to alter the black and white contrast of the subject and is exactly analogous to selecting the right grade of paper in monochrome work.

The exposures for the colour printing bromides are obtained in the normal way by balancing the grey scale and giving sufficient exposure to produce a slight density in the lightest parts of the bromides. The apparent contrast will be much less than normal and has to be estimated by experience. It's primary function now is to control the saturation (vividness) of the colours.

For direct separation negatives it is best to make three masks from the grey printer negative and bind one of these in contact with each of the separation negatives before making the bromide prints. The grey printer bromide is made from the grey printer negative.

Although it is possible to subtract nearly all the black and white contrast from the separation negatives or transparency by making the white light mask to a gamma of unity, this leads to the following practical difficulties.

(*a*) In the case of a transparency the mask may easily have a density range of nearly 2.0 which on most plates cannot be recorded on the straight portion of the characteristic curve.

(*b*) The registration of a high contrast mask needs to be very exact.

(*c*) The grey printer negative at the best is never more than approximate to the theoretical ideal, and heavy masking may lead to important errors in colour rendering.

(*d*) Complete masking will eliminate nearly all contrast in any grey scale included with the subject. It is thus impossible to check whether the separation negatives are balanced in contrast.

(*e*) It is difficult to estimate the correct contrast and density for the colour printing bromides.

(*f*) The colour images are relatively thin and flat. This makes it difficult to obtain good registration when assembling the print.

IDEAL COLOUR REPRODUCTION

The Carbro process with the normal masking system is capable of producing a very high fidelity of colour reproduction from direct separation negatives. Obvious errors which do occur are nearly always caused by faults in technique, such as incorrect colour balance, or difference in contrast between the three images, or a poor set of separation negatives. The average worker is therefore well advised to leave it at that and where necessary to correct small errors by methods described in pages 38 and 85. This section is written for those who wish to attempt facsimile reproduction, or who, like the author, have an incurable urge for delving more deeply into the whys and wherefores of the process.

LIMITS OF ACCURACY

The would-be experimenter must be warned at the outset that while it is fairly easy to standardise the process so that it is possible to produce prints which are almost alike, there are a host of factors which make it almost impossible to control the process within narrower limits than would correspond to 4 per cent in the bromide exposure. It is a failure to realise this and the fact that correction of one error frequently produces another of greater magnitude which so often makes theoretical work of little practical value.

The main factors which affect the theoretical accuracy of colour reproduction can be grouped under the following headings :—

(*a*) The transmission curves of the taking filters and spectral sensitivity of the negative material in relation to the dyes used in making the print.

(*b*) The spectral characteristics of the pigment dyes.

(*c*) The over-all tone and colour reproduction relationship of the process, as affected by

(i) The shape of the characteristic curves of the negative material, the bromide paper, the pigment images and the lens flare factor.

(ii) The viewing conditions of the print.

FILTERS AND SPECTRAL SENSITIVITY OF NEGATIVE EMULSION

The first factor is within the province of the physicist and the practical worker cannot hope to do much more than appreciate the problems involved. A very brief summary of these is given below.

Although it is often thought that there are only three bands of the spectrum which can be used for additive synthesis, there are in fact a very large number of primaries, the criterion being that none of the three can be matched by any mixture of the other two.

These primaries may consist either of three narrow saturated spectrum lines, or of wide bands occupying about one-third of the visible spectrum. The choice of the latter type is necessary in practice for additive synthesis because narrow bands would severely restrict the amount of light which could be passed by the filter elements, and wider ones on unsaturated narrow lines would not allow the reproduction of saturated colours.

In subtractive synthesis the function of a dye is to absorb the complementary colour and transmit the other two primaries. A little thought will show that it would be impossible to produce a black (a complete absorption of all light) unless the printing dyes together were capable

of absorbing the whole of the visible spectrum. Hence, unless we use a grey printer (p. 156), approximately one-third of the spectrum must be absorbed by each printing dye. Now the function of the taking filters must be to control the amounts of cyan, magenta and yellow which are to be printed. They must also be capable of analysing narrow bands of the spectrum. Both these conditions make it necessary that they will cover the whole of the visible spectrum.

The mixtures of additive primaries which will visually match any colour in the spectrum can be expressed in the form of mixture curves (p. 169). It will be noted that in some parts the curves have negative values ; this implies that a perfect match cannot be obtained unless an amount of the primary equal to its negative value is added to the colour we wish to match in order to decrease its saturation.

The first set of mixture curves were established as a mean from several people's observations. Once this had been done it was found possible to calculate the curves for any set of primaries. For the wide band primaries the negative portions of the curves are greatly increased and hence it becomes impossible to equal the saturation (vividness) of spectral colours. Fortunately in nature very few highly saturated colours occur, and the limitations imposed by the wide band primaries are seldom much of a handicap, although this point is worth bearing in mind.

Yule has shown that for perfect colour reproduction two criteria must be satisfied :—

(*a*) The process should be able accurately to reproduce the three colours it uses for printing. This can be arranged by suitable masking.

(*b*) Visually identical colours should be rendered identically. This can only be so if the combination of the spectral sensitivity of the taking filters and negative emulsion follow some set of mixture

curves. (The primaries real or unreal which control the process are then those from which the mixture curves are derived.)

Fortunately the standard sets of tricolour filters when used with the average negative material are for all practical purposes reasonably satisfactory in this respect.

TONE REPRODUCTION

The reproduction curve for the whole process should approximate to a straight line, and have a gamma of roughly unity. This is equivalent to saying that when the print is looked at under normal viewing conditions the grey scale should appear identical with the original viewed from the position of the camera. Even if the negative material has a perfectly straight line characteristic curve and the densities of the separation negatives are all within this region, flare effect in the camera lens introduces a toe to the reproduction curve. This being so, a steep shoulder in the bromide characteristic curve may be no disadvantage in so far as it tends to compensate for the toe in the negatives. Unfortunately we have also to take into account the reproduction characteristics of the pigment image.

Under normal conditions the errors introduced from this cause are not very great and a complete analysis of the problem would hardly be worth while. It is, however, quite easy to make a rough check by comparing the grey scale in a print with the original. It is worth noting that if the grey scale was placed at some distance from the camera, its apparent contrast would be considerably less than if seen at a closer range and a test made under the former conditions would not be very satisfactory.

If when comparing the print grey scale with the original the density difference between the lighter steps was less than

in the original, the print would of course appear flat in the highlights. The effects on colour reproduction would be :

(*a*) Light desaturated colours would become more desaturated.

(*b*) The hue of colours which were reproduced in a light density in more than one of the bromides would be falsified.

CHARACTERISTICS OF THE PIGMENT DYES

The proper function of any one of the three pigment dyes is to absorb its complementary filter colour in amounts which bear a direct relation to the quantity of the dye present, but to transmit completely the other two primaries.

As has already been pointed out on p. 136, none of the dyes succeed in doing this, although the yellow is reasonably satisfactory. The chief defects are :

(*a*) Failure to transmit or reflect the non-complementary primaries, e.g., the cyan absorbs quite a lot of green.

(*b*) A tendency for the relative absorptions of the dyes to alter with the density, e.g., a very heavy density of cyan usually absorbs almost as much green as blue.

(*c*) Failure to absorb the complementary colour in direct relation to the amount of dye present, i.e., densities are not strictly additive.

The first of these defects gives rise to the most important errors in the process and is the only one which need concern the practical worker. Fortunately it is possible to compensate for this by masking. In effect the analysis filters then control dyes which behave much more nearly like the ideal dyes. We cannot, however, match any colour which could not be matched by a physical mixture of the dyes. This means that due to the poor dye reflection properties and to the negative regions postulated by the

mixture curves, saturated (vivid) colours if rendered with correct saturation will not be as luminous as they would be when using ideal dyes.

All masking systems are a compromise between what is theoretically desirable and what in practice can be done without too much labour and with sufficient accuracy to make the results worth while. There are three factors to consider :—

(*a*) The effect on the rendering of hue.
(*b*) The effect on colour saturation.
(*c*) The effect on tone reproduction.

With any normal masking system it is impossible to correct for hue without at the same time increasing the saturation. Similarly any alteration in contrast will also affect the hue (see p. 131). The usual procedure with masking is therefore to maintain correct tone reproduction by ensuring that the over-all gamma of the whole process is approximately unity (grey scale in original = grey scale in print) and obtaining the most satisfactory compromise for (*a*) and (*b*).

The most obvious way of testing out a masking system is to set up a comprehensive colour chart, photograph it, and then compare the colour print with the original. While this method is excellent for finding out the errors which occur, it does not show what is necessary in order to improve the results, and a trial and error method of altering the masks is extremely laborious.

Clearly any colour process should be able accurately to reproduce the three colours used for printing. If this can be done, the chances are that all major errors in colour reproduction will be eliminated, although the second criterion for perfect colour reproduction, i.e., that visually identical colours must be reproduced identically, will not necessarily be satisfied. If then we make separations from

a chart consisting of cyan, magenta and yellow colour patches and assume that no errors are introduced between the separation negative stage and the colour reliefs, the densities of each of the negatives ought to be such that it only prints its complementary colour.

We can therefore tabulate the requirements as below. The term unprintable is of course a relative one and will depend on the exposure of the bromide.

REQUIREMENTS FOR PERFECT SEPARATION

Colour	*Density in* *Red Filter Negative*	*Green Filter Negative*	*Blue Filter Negative*
Cyan patch	Say 0·3	Unprintable	Unprintable
Magenta patch	Unprintable.	Say 0·3	Unprintable
Yellow patch	Unprintable.	Unprintable	Say 0·3

If the original cyan magenta and yellow patches were of equivalent density, i.e., when superimposed produce grey, then :

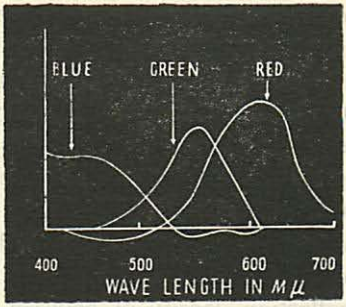
(*a*) The density difference as recorded in the negatives between the complementary coloured patch and the other two patches should be the same in each case.

(*b*) If the grey scale is balanced, the minimum densities should be the same in all negatives.

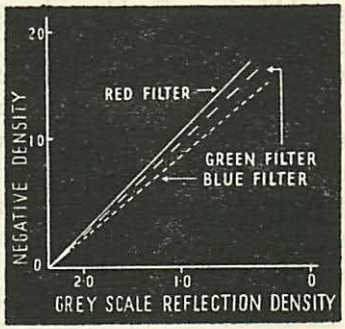
Owing to the imperfections of the dyes, (*a*) above will not be realised, but by masking it is possible to approximate to the required result. This provides a useful practical method of checking up on two alternative masking systems, and is also the theory on which the calculations for masking systems described later are based.

THE TEST CHART

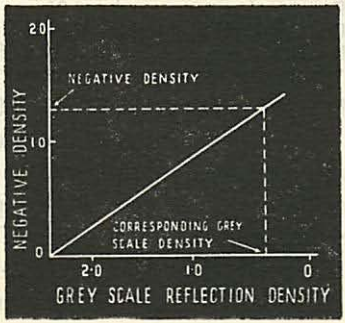
The test chart should consist of patches of each of the three printing colours and a grey scale. The patches should be made by the Carbro process from strips of bromide paper which have received roughly the same printing



Colour mixture curves. Mixtures of these additive primaries can be made to match any spectrum colour. The negative values imply that for a perfect match the colour to be matched has to be desaturated (p. 164).



Equivalent reflection densities. In this graph the densities of the grey scale are plotted against the negative densities for the red, green, and blue filter negatives. Ideally, the three curves should coincide (p. 170).



Equivalent neutral reflection densities. To find the E.N.R. density, a horizontal line is drawn from the negative density until it cuts the appropriate filter curve, and a vertical line dropped to the grey scale density below (p. 171).

exposure and are a medium grey density. After development the pigment images can be transferred direct to the soluble temporary support, and the final transfer omitted. Colour patches cut direct from the pigment papers are quite useless as there the densities of the dyes are much greater than when used for a colour print, and in this state they have completely different spectral characteristics. As a rough guide the cyan patch when viewed through the complementary taking filter should have an equivalent reflection density of between 1 and 1.3, which is rather lighter than the darkest step of the grey scale. The grey scale should have several steps ranging from white to a good black, preferably with a glazed surface. A convenient size is about $6\frac{3}{4}$ inches ; anything much larger will be more difficult to illuminate evenly when photographing it.

When the test chart has been completed, pin it up on the wall against a black background, light it perfectly evenly and photograph with the normal tricolour filters. Develop the negatives to a gamma of about 1 and then measure up the densities of the colour patches and grey scale, tabulating as under :—

DENSITIES OF TEST CHART

	Red Filter Negative	*Green Filter Negative*	*Blue Filter Negative*
Density of cyan patch	0.82	1.20	1.36
Density of magenta patch	1.36	1.03	1.38
Density of yellow patch	1.37	1.30	1.11
Density of grey scale	0.61 to 1.38	0.55 to 1.33	0.61 to 1.50

EQUIVALENT REFLECTION DENSITIES

If the reflection densities of the steps of the grey scale are measured, a graph can be drawn relating the densities of the grey scale steps as they appear in each of the negatives with the reflection densities of the grey scale itself (p. 169). If the filter factors and times of development were such that the separation negatives are in balance, the curves drawn

for each negative will coincide. From this graph the *equivalent neutral reflection density* (E.N.R. for short) of any of the colour patches through a given filter can be found. This is done by marking the density on the vertical axis, drawing an horizontal line until it cuts the appropriate filter negative curve, and then reading off the density on the grey scale which is vertically below this point (p. 169).

By this method a table such as that given below may be compiled. If no means are available of measuring the reflection densities of the grey scale, we can assume that the lightest step is zero, and the darkest 1.5. This will not affect the calculations provided that the negative characteristic curves are straight lines over the part of the graph which is used for finding the equivalent reflection densities of the colour patches.

EQUIVALENT REFLECTION DENSITIES

	Red Filter	*Green Filter*	*Blue Filter*
Cyan patch	1.20	0.32	0.29
Magenta patch	0.04	0.67	0.25
Yellow patch	0.03	0.10	0.74
Vertical Total	1.27	1.09	1.28

It will be seen that the totals for each of the vertical columns in the above table are 1.27 for the red filter negative, 1.09 for the green, and 1.28 for the blue. Now if the colour patches had been of densities which, if superimposed, produced grey, they should when taken together produce, roughly, equal amounts of red, green and blue light, and hence the sum of the reflection densities for each filter should be the same ; say equal to unity.

The figures for the reflection densities of each of the pigments must be adjusted to meet this condition.

This may be done by multiplying each horizontal line in the table by a suitable factor. Let α, β and γ be these factors for the cyan, magenta and yellow respectively. Then

by adding up each vertical column in the table on p. 171 and putting it equal to unity, we get the following equations :—

$$1.20\ \alpha + 0.04\ \beta + 0.03\ \gamma = 1$$
$$0.32\ \alpha + 0.67\ \beta + 0.10\ \gamma = 1$$
$$0.29\ \alpha + 0.25\ \beta + 0.74\ \gamma = 1$$

from which

$$\alpha = .78$$
$$\beta = 1.00$$
$$\gamma = .70$$

The corrected E.N.R. densities are tabulated below :

CORRECTED E.N.R. DENSITIES

	Red Filter	*Green Filter*	*Blue Filter*
Cyan patch	$C_r = 0.94$	$C_g = 0.25$	$C_b = 0.23$
Magenta patch	$M_r = 0.04$	$M_g = 0.68$	$M_b = 0.25$
Yellow patch	$Y_r = 0.02$	$Y_g = 0.07$	$Y_b = 0.52$
Total	1.00	1.00	1.00

The coefficients C_r, C_g, etc., are needed for making calculations for correction masks and are applicable to the dye concentrations which have to be used in practice to produce a proper scale of greys.

IDEAL REFLECTION DENSITIES

If we wish to compare the dyes with the theoretical ideal, the concentrations should be balanced so that all dyes fulfil a part of their function correctly by absorbing the same amount of their complementary colours. To do this multiply the E.N.R. densities of each of the pigments by factors which will bring the maximum density to unity in each case. This has been done in the table on p. 173.

E.N.R. DENSITIES FOR COMPARISON WITH IDEAL DYES

	Red Filter	*Green Filter*	*Blue Filter*
Cyan patch	1.00	0.27	0.24
Magenta patch	0.06	1.00	0.37
Yellow patch	0.04	0.13	1.00

From these figures it will be seen that

(*a*) The cyan does not reflect as much green or blue as it should.

(*b*) The magenta does not reflect as much blue as it should.

(*c*) The yellow is reasonably satisfactory.

In order to correct all errors completely by masking, up to a maximum of six-colour correcting masks would be required. All of these and the separation negatives would have to be developed to different gammas. In practice such a complicated procedure would not produce worth-while results and one of the following systems is recommended :—

(*a*) A three mask system in which all masks are of the same contrast, two of the masks being for colour correction and the third for equalising the contrast of one of the negatives.

(*b*) A two-mask system giving rather better correction in which the masks and separation negatives all have to be made to different gammas.

If a two or three mask system is used, complete theoretical accuracy in reproduction cannot be obtained. The best compromise is probably to correct as near as possible for hue and to disregard the errors in saturation (vividness of the colours).

With nearly all dyes the most important masks are the red to green filter mask, and the green to blue filter mask.

Theoretically, almost perfect reproduction of hue can be obtained with the two mask system if the yellow pigment is assumed correct. So a colour patch in the chart, when

recorded equally in two of the negatives, should also produce equal densities in the print. In practice the vital requirement is that the separation negative characteristic curves should be similar and remain so when developed or intensified to give the different gammas.

THE TWO-MASK SYSTEM

The calculations for a two-mask system based on these assumptions are as follows :—

Let d = *gamma of mask made from red filter negative and registered with green filter negative.*

e = *gamma of mask made from green filter negative and registered with blue filter negative.*

and let the relative gammas to which the separation negatives must be developed to give equal contrast after masking be as follows :—

Red filter = 1
Green filter = p
Blue filter = q

The relative E.N.R. densities of the masked and unmasked negatives can be set out in tabular form. Since these are expressed as equivalent reflection densities they will also be directly proportional to the quantity of pigment or dye which will be printed in each of the corresponding colour images.

RELATIVE E.N.R. DENSITIES

Designation of Negative	*RELATIVE E.N.R. DENSITY OF*			*Relative Quantity of Pigment or Dye in Print*
	Negative	*Mask*	*Masked Negative*	
Red filter	x	dx	No mask	Cyan x
Green filter	py	epy	py − dx	Magenta py − dx
Blue filter	qz	—	pz − epy	Yellow pz − epy

Now if we write down the reflection coefficients of the dyes and then multiply them by the quantities of pigment or dye which will be used in the print we can find the corresponding E.N.R. densities of each of the colour part images (Table below). The dye constants are C_r C_g etc.

Assuming that the densities of the colour part images are additive when superimposed* we can also find the reflection densities to Red, Green and Blue light of the final print. This is done by adding together the densities of each of the part images (see Table below). This is extremely useful since, as will be shown later, we can see how well the process is likely to reproduce any given colour.

E.N.R. DENSITIES IN THE PRINT

Colour of Pigment or Dye	*Reflection Coefficients for Dyes*		
	To Red	*To Green*	*To Blue*
Cyan	$C_r x$	$C_g x$	$C_b x$
Magenta	$M_r (py-dx)$	$M_g (py-dx)$	$M_b (py-dx)$
Yellow	$Y_r (pz-epy)$	$Y_g (pz-epy)$	$Y_b (pz-epy)$
E.N.R. Density of *Final Print*	$C_r x +$ $M_r (py-dx) +$ $Y_r (pz-epy)$	$C_g x +$ $M_g (py-dx) +$ $Y_g (pz-epy)$	$C_b x +$ $M_b (py-dx) +$ $Y_b (pz-epy)$

The next step is to write down and solve equations which will give numerical values for d, e, p and q.

Since the strengths of the dyes are balanced so that in equal quantities they produce grey, the contrast of the masked negatives must be equal in order to reproduce a neutral grey scale. Then from the table on p. 174, if $x = 1$, $y = 1$ and $z = 1$

(i) $p - d = 1$, or $p = 1 + d$
(ii) $q - ep = 1$, or $q = 1 + ep$

For a blue green having an E.N.R. density difference

* This is a very nearly true for dye transfer but only approximately so for carbro as the carbro part images are not completely transparent and have appreciable thickness.

in the separation negatives of (1, 0, 0) we have (assuming Y_r and $Y_g = 0$)

Green E.N.R. density in print $= C_g - M_g\,d$
Blue E.N.R. density in print $= C_b - M_b\,d$

To obtain the best possible rendering of hue (p. 173), these must be equal, therefore $C_g - M_g\,d = C_b - M_b\,d$

(iii) *hence* $d = \dfrac{C_g - C_b}{M_g - M_b}$

Similarly for a magenta (0, 1, 0) we have (neglecting the Y_r term which is zero)

(iv) $M_r\,p = M_b\,p - Y_b\,ep,$

hence $e = \dfrac{M_b - M_r}{Y_b}$

Substituting actual values from the table on p. 172 in these equations, we get :

$$d = \frac{0.25 - 0.23}{0.68 - 0.25} = \frac{0.02}{0.43} = 0.04$$

$$e = \frac{0.25 - 0.04}{0.52} = \frac{0.21}{0.52} = 0.4$$

$$p = 1 + 0.04 = 1.04$$

$$q = 1 + 1.04 \times 0.4 = 1.4$$

Hence the three separation negatives should be developed so that their contrasts are in the ratio of : red filter 1 ; green filter 1.04 ; blue filter 1.4 ; and masked as follows :—

red filter :	No mask
green filter :	Mask of gamma 0.04 made from the red filter negative
blue filter :	Mask of gamma 0.4 made from the green filter negative.

Obviously a mask of gamma 0.04 is impracticable and quite unnecessary and can therefore be omitted.

THEORETICAL ACCURACY OF REPRODUCTION

In order to find out the accuracy with which the calculated masking system reproduces any colour, we only have to insert numerical values into the equations for the colour E.N.R. densities of the print and to compare these with the original.

For example, if a colour patch which is being photographed has E.N.R. densities to red, green and blue light of 1, 1 and 0 respectively, the corresponding E.N.R. densities in the print are given by :—

$$R = C_r\,x + M_r\,(py - dx) + Y_r\,(pz - epy)$$
$$G = C_g\,x + M_g\,(py - dx) + Y_g\,(qz - epy)$$
$$B = C_b\,x + M_b\,(py - dx) + Y_b\,(qz - epy)$$

Substituting values for the dye constants C_r M_r etc., from the table on p. 172 we get :

$$R = 0.94\,x + 0.032\,y + 0.028z$$
$$G = 0.25\,x + 0.652\,y + 0.098z$$
$$B = 0.23\,x + 0.042\,y + 0.728z$$

Now we put x and y and z equal to the E.N.R. densities of the original (In this example $x = 1, y = 1, z = 0$).

Then the corresponding E.N.R. densities in the print will be :—

$$R = .94 + .032 = .972$$
$$G = .25 + .652 = .902$$
$$B = .23 + .042 = .272$$

If the subject is neutral in colour, it will have equal density to red, green, and blue light, hence $x = y = z$. It will be found that under these conditions the equations give equal values and that R, G, and B in the print have the same values as the original. This shows that the grey scale will be correctly rendered both as regards colour and tone contrast. In actual practice the over-all contrast of the process will depend not only on the separation negatives but on the flare factor of the lens, on the bromides, and on

the sensitiser. The last three variables must be adjusted so that the tone range of the grey scale in the print approximates to that in the original. Failure to do so not only falsifies the tone rendering of the print but also affects saturation, and, to a small extent, hue. (See p. 131.)

The balanced contrast system must necessarily be a compromise between the contrast required in the mask correcting for the poor green reflection of the cyan dye, and that required to correct for the inadequate reflection of the blue by the magenta dye.

The approximate gamma for these two masks can easily be found from the figures already worked out for the two-mask system.

The mask for the green filter negative requires a gamma of $\frac{d}{p} = \frac{0.04}{1.04} = 0.04$

and that for the blue filter negative $\frac{ep}{q} = 0.4 \times \frac{1.04}{1.4} = 0.30$

As all masks must have the same contrast an average between these two figures would be likely to produce the best results. In this particular case the obvious answer is to dispense with the colour correcting mask for the green filter negative and to use another contrast reducing mask. This would then give the same results as the two-mask system.

It will be seen that for the normal three-mask system using two-colour correcting masks and one contrast reducing mask of gammas = 0.33, the results (for the pigment papers tested) are definitely inferior in colour rendering to that obtained with one colour correction mask on the blue filter negative.

PRACTICAL EVALUATION

The table on p. 180–181 shows figures worked out for a few colours

(*a*) with unmasked negatives,
(*b*) with the two-mask system,
(*c*) with a three-mask system, 33 per cent masking,
(*d*) with the two-mask system and an over-all contrast of 25 per cent greater than the correct value.

The results are of course only applicable to the pigment papers tested and can also be affected by the spectral sensitivity of the plates, the characteristics of the taking filters, the type of light used for illuminating the test chart and the amount of pigment in the colour patches.

As a rough method of comparison the percentage error in hue has been calculated on the amount of unwanted primary which would be reflected in 100 units of coloured light. (The amount of any primary reflected being proportional to 1/antilog D where D is the reflection density to that primary.) The figures for saturation are obtained from the ratio of coloured light to total light reflected.

Although a complete masking system is unlikely to be of any practical use, it may be of interest to note that it can be worked out by solving three simultaneous equations :—

$$R = C_r\,C + M_r\,M + Y_r\,Y \quad \ldots\ldots\ldots\text{(i)}$$
$$G = C_g\,C + M_g\,M + Y_g\,Y \quad \ldots\ldots\ldots\text{(ii)}$$
$$B = C_b\,C + M_b\,M + Y_b\,Y \quad \ldots\ldots\ldots\text{(iii)}$$

R, G, and B are the E.N.R. densities to red, green and blue light required in the final print.

C, M, and Y are the quantities of cyan, magenta, and yellow required to give these densities and hence the E.N.R. densities required in the negatives after masking. C_r M_r etc., are the dye constants as in the Table on p. 172.

The solution to these equations after substituting numerical values for the dye constants is :

$$C = 1.09\ R - 0.05\ G - 0.04\ B \quad \ldots\ldots\ldots (i)$$
$$M = 1.57\ G - 0.37\ R - 0.20\ B \quad \ldots\ldots\ldots (ii)$$
$$Y = 2.04\ B - 0.30\ R - 0.74\ G \quad \ldots\ldots\ldots (iii)$$

Hence the magenta printer must have a relative contrast of 1.57 and requires masking with a mask made from the red filter negative developed to a gamma of 0.37, and with a mask made from the blue filter negative of gamma 0.20. The contrast for the other negatives and their masks can be read from the equations in similar manner.

The dye constants as used in the Table on p. 172 give some idea of the masking necessary, but this method is rather dangerous. For instance, the cyan which ought to reflect green light perfectly has a density to green of 0.25. By a suitable mask we may remove an equivalent amount from the 0.68 of magenta which is absorbing green, but the mask will also affect the unwanted 0.25 density to blue which the magenta pigment possesses. Moreover, since the densities to green and blue of the cyan pigment are nearly equal it does not help to correct the one without the other. The only satisfactory method is to work out the problem mathematically, altering the values to suit the particular masking system it is proposed to adopt, and then to calculate values from the equations for some selected colours.

TYPICAL REPRODUCTION : UNMASKED NEGATIVES

Original				*Colour Print*				
Reflection Density to			*Colour*	*Reflection Density to*			*Error in Hue*	*Relative Saturation*
R	*G*	*B*		*R*	*G*	*B*		
1	0	0	Blue Green	0.94	0.25	0.23	3%	73%
0	1	0	Magenta	0.04	0.68	0.25	33%	63%
0	0	1	Yellow	0.02	0.07	0.52	8%	57%
0	1	1	Red	0.06	0.75	0.77	1%	58%
1	0	1	Green	0.96	0.32	0.75	15%	56%
1	1	0	Blue	0.98	0.93	0.48	4%	43%
1	1	1	Neutral	1.00	1.00	1.00	—	100%

TYPICAL REPRODUCTION : TWO-MASK SYSTEM

Original				*Colour Print*				
Reflection Density to			*Colour*	*Reflection Density to*			*Error in Hue*	*Relative Saturation*
R	*G*	*B*		*R*	*G*	*B*		
1	0	0	Blue Green	0.94	0.25	0.23	3%	73%
0	1	0	Magenta	0.03	0.65	0.04	1%	68%
0	0	1	Yellow	0.03	0.10	0.73	10%	71%
0	1	1	Red	0.06	0.75	0.77	1%	58%
1	0	1	Green	0.97	0.35	0.96	1%	51%
1	1	0	Blue	0.97	0.90	0.27	4%	58%
1	1	1	Neutral	1.00	1.00	1.00	—	100%

TYPICAL REPRODUCTION : THREE-MASK SYSTEM, 33 PER CENT MASKS

Original				*Colour Print*				
Reflection Density to			*Colour*	*Reflection Density to*			*Error in Hue*	*Relative Saturation*
R	*G*	*B*		*R*	*G*	*B*		
1	0	0	Blue Green	0.92	0.09	0.10	13%	81%
0	1	0	Magenta	0.05	0.98	0.11	8%	84%
0	0	1	Yellow	0.03	0.10	0.78	10%	73%
0	1	1	Red	0.08	1.09	0.89	6%	77%
1	0	1	Green	0.95	0.01	0.88	2%	72%
1	1	0	Blue	0.97	0.89	0.21	4%	63%
1	1	1	Neutral	1.00	1.00	1.00	—	100%

TYPICAL REPRODUCTION : TWO-MASK SYSTEM, CONTRAST INCREASED 25 PER CENT

Original				*Colour Print*				
Reflection Density to			*Colour*	*Reflection Density to*			*Error in Hue*	*Relative Saturation*
R	*G*	*B*		*R*	*G*	*B*		
1	0	0	Blue Green	1.17	0.31	0.27	4%	76%
0	1	0	Magenta	0.04	0.81	0.05	2%	76%
0	0	1	Yellow	0.04	0.13	0.71	12%	80%
0	1	1	Red	0.08	0.94	0.96	1%	69%
1	0	1	Green	1.21	0.44	1.20	0.1%	85%
1	1	0	Blue	1.21	1.13	0.34	0.3%	87%
1	1	1	Neutral	1.25	1.25	1.25	25%	125%

TRANSPARENCIES

The problem of devising a successful masking system for transparencies is not an easy one as there are a large number of variable factors. For most workers the best solution is to accept the makers' recommendations for masking and hope for the best ; but for those working under reasonably standardised conditions it may be worth while carrying out some initial tests.

The effective dye constants to be used for calculating the masking system can be worked out in exactly the same way as described previously, ignoring the fact that the separation negatives were made indirectly from a transparency.

Unfortunately the dye constants may vary with the density with which they are recorded in the transparency, and when making the test two or three transparencies should be taken, giving different exposures, and the results averaged. It is possible to save time by making three or four steps of different density in each of the colour patches, but this introduces errors because the reflections of the dyes vary slightly with their densities.

The test may be used in two ways ; either as a check on the standard transparency masking system to find out whether any additional masking on the separation negatives is advisable, or as a means of calculating a masking system for the unmasked transparency. The latter may be applied to the separation negatives, or transparency masks can be made through the separation filters. Both these masking methods can produce roughly the same results, e.g. : If a red filter transparency mask is used when making the red and green records it is equivalent to masking these negatives with masks made from the red record.

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